Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Reallocation of the 216-220 MHz,	)	ET Docket No. 02-08
1390-1369 MHz, 1427-1429 MHz	)	RM-9267
1429-1432 MHz, 1432-1435 MHz,	)	RM-9692
1670-1675 MHz,	)	RM-9797
and 2385-2390 MHz	)	RM-9854
Government Transfer Bands	)	RM-9882

To: The Commission

Reply Comments of InsideTrax™

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SUMMARY

InsideTrax™ files these reply comments in response to a number of positions taken by commenting parties on proposals and positions tentatively adopted by the Commission in its Notice of Proposed Rule Making.

Specifically, InsideTrax™ stands with AeroAstro and ArrayComm in supporting the Commission's adoption of a nationwide allocation of the 1670-1675 MHz band. Along with ArrayComm, InsideTrax™ also reiterates the position that licenses should be for a term of ten years. InsideTrax™ also provides the Commission with further technical analysis and comments in response to both of these parties on the technical rules for the 1670-1675 MHz band.

Finally, InsideTrax™ addresses the concerns raised by ArrayComm with regard to the public safety bidding credit and reminds the Commission of the critical importance of considering public interest externalities that are not directly reflected by the market cash value, and again asks it to adopt public safety bidding credits to ensure that the spectrum be put to work for the public interest.

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To: The Commission

Reply Comments of InsideTrax™

I. Introduction

InsideTrax ("InsideTrax™")[1] by counsel and pursuant to Section 1.415(c) of the Commission's Rules, hereby submits its reply comments in the above captioned rule making proceeding.[2] InsideTrax™ continues to participate in this proceeding, seeking to address both technical and legal issues related to proposed licensing of the 1670-1675 MHz band. As stated in its previously filed petition and comments, InsideTrax™ believes strongly that the public interest should be the major consideration of the Commission in licensing new services in the 1670-1675 MHz band. In support thereof, the following reply comments – intended to address matters only as they relate to the 1670-1675 MHz band – are respectfully submitted:

[1] Formerly MicroTrax™

[2] *Reallocation of the 216-220 MHz, 1390-1369 MHz, 1427-1429 MHz 1429-1432 MHz, 1432-1435 MHz, 1670-1675 MHz, and 2385-2390 MHz Government Transfer Bands*, WT Docket No. 02-08, Notice of Proposed Rule Making, FCC 02-15 (released February 6, 2002) ("NPRM").

II. Licensing Plan

Generally, InsideTrax™ supports the comments of AeroAstro and ArrayComm with regard to the appropriateness of applying Part 27, the essential need for nationwide licensing, and the importance of licensing the spectrum as a unified 5 MHz block. InsideTrax™ highlights the fact that these three parties – the only ones to express substantial interest in the 1670-1675 MHz block – have advanced these same positions throughout this proceeding with no opposition.

As to the terms of the license itself, InsideTrax™ and ArrayComm both support a 10 year term with a renewal expectancy based on a showing of substantial service.

A. Rules Flexibility

InsideTrax™ reiterates its support for the Commission's proposal to apply the regulatory framework of Part 27 to the 1670-1675 MHz band.[3] In doing so, InsideTrax™ thus joins with ArrayComm and AeroAstro in recognizing that Part 27 would provide an appropriate amount of flexibility to licensees so that a range of new and innovative technologies may use the reallocated spectrum.[4] Of course, this support is based on the assumption that the Commission will also adopt similarly appropriate and flexible technical rules, as discussed in Section IV of these Reply Comments.

B. Adoption of National Licensing for the Full 5 MHz Block between 1670-1675 MHz Is Essential to Maximizing the Benefit to the Public

InsideTrax™ also joins with AeroAstro and ArrayComm in supporting the Commission's tentative decision to license the 1670-1675 MHz band on a nationwide basis.[5] All parties note that the services each plans to provide on this band would operate most effectively if the users of

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[3] *See* NPRM at para 77.
[4] *See* NPRM at para. 33; *see also* Comments of ArrayComm, Inc. at 6, filed on March 4, 2002 ("Comments of ArrayComm") and Comments of AeroAstro, Inc., at 4-5., filed on March 4, 2002 ("Comments of AeroAstro").
[5] *See* NPRM at para. 33; *see also* Comments of ArrayComm at 5, Comments of AeroAstro at 3.

such services are not restricted to certain markets or parts of the country by a patchwork allocation of spectrum.[6]

The Commission should deny the request of the National Telecommunications Cooperative Association ("NTCA") to grant all licenses by "small geographic areas, such as Metropolitan Statistical Areas (MSAs) and Rural Statistical Areas (RSAs)."[7] The NTCA provided no substantial factual analysis or reasoning to overcome the proceeding record, which clearly establishes the benefits of a nationwide allocation for the 1670-1675 MHz band.

InsideTrax™ continues to support – as do AeroAstro and ArrayComm – the Commission's tentative conclusion that the 1670-1675 MHz band should be auctioned as a single five MHz block.[8] The full five MHz block is the *minimum* necessary bandwidth for the present prospective service providers to provide innovative and robust services.[9] Finally, InsideTrax™ supports AeroAstro's and ArrayComm's rejection of band managers as eligible licensees for the 1670-1675 MHz band.[10] Given the intentions of each and all of the parties that have indicated a serious interest in this spectrum, to use it as a single, nationwide allocation, band managers would be superfluous.

C. Ten Year License Terms with a Renewal Expectancy are Appropriate

InsideTrax™ and ArrayComm both support the Commission's proposal for 10 year license terms with renewal expectancies similar to those currently in place for cellular and PCS licensees.[11] Such license terms would give investors sufficient assurance to commit capital,

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[6] *Id.*
[7] *See* Comments of the National Telecommunications Cooperative Association at 2 (March 4, 2002).
[8] *See* NPRM at para. 35.
[9] *See* NPRM at para. 74 and Comments of ArrayComm at 12-14.
[10] *See* Comments of ArrayComm at 8-10; Comments of AeroAstro at 5.
[11] *See* NPRM at para. 86; Comments of ArrayComm at 12.

allow licensees enough time to institute service, and provide the Commission with a means to enforce its rules.

While InsideTrax™ does find some merit in AeroAstro's proposal for a 20 year license, it rejects modified build out standards proposed by AeroAstro. More specifically, InsideTrax™ disagrees with AeroAstro's request that the Commission adopt build out standards that do not require actual "substantial service" but rather "substantial progress toward substantial service."[12] Such a standard would potentially allow licensees to block otherwise-useful spectrum from use for decades while the licensee attempted to develop technology that may well turn out to be obsolete by the end of the license term. To allow such a result would be tantamount to the rejection of any principle that society benefits by placing precious resources in service as quickly as possible. Rather, it would elevate to insurmountable, the concept that spectrum value is wholly dependent on determining who will pay the most money, even if that payment is made to park the public resource out of effective public use.

III. Auctions and the Public Interest

A. Public Safety Bidding Credits Account for Substantial Externalities Not Presently Captured by the Commission's Auctions.

In the NPRM, the Commission announced that it was open to the possibility of instituting a bidding credit for those parties who proposed uses of the spectrum that would enhance public safety and invited comments on this possibility.[13] InsideTrax™ believes that the record of this proceeding contains a solid and persuasive presentation of the economic analysis and the public interest factors that lead it to propose Commission adoption of a "public safety bidding credit." As such, it will not repeat the details of its analysis, but respond directly to ArrayComm- the

[12] *See* Comments of AeroAstro at 7.
[13] *See* NPRM at para. 151.

single commenting party that opposes such a mechanism to account for public safety externalities in auctions.

ArrayComm appears to have three objections to the institution of such a credit. They can be summarized as follows: 1) public safety bidding credits encourage the reversion of spectrum to "quasi-government[al] use"[14], 2) public safety bidding credits are "unfair",[15] and 3) such a credit is too "unwieldy" and complicated.[16] All of these objections are based on a mischaracterization or misunderstanding of the public safety bidding credits proposal.

First, public safety bidding credits do not encourage the reversion of spectrum to quasi-governmental use, but rather account for clear external benefits that are created by private sector use that also provides public safety applications that the public does not have to pay for with tax collected dollars – benefits that would not be otherwise captured in auctions. Such an accounting is essential to the "truly free, unencumbered market" that ArrayComm cites as a goal of auctions.[17] As any economist will attest, - a fully functioning free market is one in which all costs and benefits are considered.

ArrayComm incorrectly characterizes the services that would be eligible for the public safety bidding credit as applications that are already exempt from auctions. This is simply untrue. Section 309(j)(2) of the United States Code exempts only public safety radio service licensees—which are almost exclusively state or local government fire and police departments—from competitive bidding.[18] There is no commercial component to these services, and the

[14] *See* ArrayComm Comments at 37.
[15] *Id.* at 37-38
[16] *Id.* at 38-39.
[17] *Id.* at 38.
[18] *See* Section 309(j)(2), which provides, in part, that:

> *"The competitive bidding authority granted by this subsection shall not apply to licenses or construction permits issued by the Commission -*

services are generally only available to government entities or their designees. InsideTrax™ acknowledges that it would be inefficient to devote this application solely to public radio service licensees. A more robust benefit to society, and the most efficient use of the spectrum, can be realized by a shared application of public safety and private applications. The public safety component is recognized in the bidding process by the proposed credit, while a great deal of the actual cost is recognized in the dollars actually paid out in the auction. InsideTrax™ believes that it can make the case for such a credit, but it has no doubt that others will also devise ways to take advantage of it and to that extent, society will be all the better off.

InsideTrax™ has clearly illustrated that the Commission should not take the express exemptions of Section 309(j)(2) as the only means by which it may recognize the substantial externalities associated with public-safety applications. Rather, the public-safety bidding credit proposed by InsideTrax™ is *complementary* to the purpose of Section 309(j)(2). Instead of encouraging the reversion of spectrum to quasi-governmental use, public safety bidding credits may help open up private sector applications to additional public safety features that might otherwise be lost to society or that were previously available only through exclusive government agency applicaiton.

Second, there is nothing "unfair" about the proposed public safety bidding credit. If anything, the proposed credit attempts to compensate for the unfair advantage gained by those commercial application providers who can quickly and easily measure the total value of their services in the marketplace. This advantage is gained at the expense of other application providers whose service also provide value to society, but that value may not be as easily or

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(A) for public safety radio services, including private internal radio services used by State and local governments and non-government entities and including emergency road services provided by not-for-profit organizations, that -
(i) are used to protect the safety of life, health, or property; and
(ii) are not made commercially available to the public;"

quickly monetized as the commercial providers' services. ArrayComm's arguments seem to boil down the fact that it – and any other bidder that does not provide a service aimed primarily at public safety – may not qualify for the public safety bidding credit. This appears to miss the central point of InsideTrax™' argument- that a public-safety bidding credit should be used in auctions as a means of accounting for the presence of very substantial externalities generated by such public safety services. The external benefits accruing to society and the economy by a service which is focused *primarily* on public safety are not likely to be otherwise recognized or captured by private parties and reflected in their valuations and bids in an auction. Should the Commission adopt a definition so broad as to include any entity providing a service that may occasionally be used for public safety service – as ArrayComm would have it do – the effect of the public safety bidding credit would be so diluted as to make it meaningless. To adopt such a broad standard would turn the credit into an unnecessary subsidy for creative characterization of proposed applications rather than an essential tool for measuring the benefits associated with a true public safety service.

Finally, a public safety bidding credit need be no more complicated than the existing small business credits that ArrayComm supports in its comments.[19] It appears that ArrayComm understands InsideTrax™' proposal to be for a public safety bidding credit that is awarded in proportion to percentage of the service that is focused on public safety. This is not the case- InsideTrax™ proposes that a uniform public safety bidding credit be awarded to any bidder whose *"sole or principle purpose of the services it intends to offer is to protect the safety of life, health, or property, and that its service will assist public officers in their missions to carry out these same functions"* or otherwise meets the criteria established by the Commission for such a credit.

[19] *See* Comments of ArrayComm at 35.

In its earlier comments, InsideTrax™ offered a definition of eligibility modeled on Section 337(f)(1), which presently defines "public safety services" for the purposes of Balanced Budget Act auctions.[20] Specifically, InsideTrax™ would require that eligible entities certify that *the sole or principle purpose of the services it intends to offer is to protect the safety of life, health, or property, and that its service will assist public officers in their missions to carry out these same functions.* Either the bidder qualifies for the credit or it does not- it is as simple as that.

In sum, ArrayComm's criticisms appear to be primarily based upon a misunderstanding of InsideTrax™' proposal, and should thus be discounted. Furthermore, no other parties raised any objection to the bidding credit. In light of the lack of any substantial opposition to the credit, and upon the well-reasoned basis established by InsideTrax™ during this proceeding, the Commission should move to adopt a public safety bidding credit for use in the auction of the 1670-1675 MHz band.

IV. 1670-1675 MHz Band Technical Issues

InsideTrax™ continues to urge the Commission to adopt its earlier proposals regarding both in and out of band emissions and power limits. While it does differ on the specific limits involved, InsideTrax™ generally supports the approach of AeroAstro with regard to in-band power and antenna limits. With regard to protection of the incumbent Federal facilities at

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[20] *Se*e In the Matter of Implementation of Sections 309(j) and 337 of the Communications Act of 1934 as Amended, 15 FCC Rcd 22709, para. 16 (2000)(*"Section 337(f)(1) provides:*

The term "public safety services" means services—

(A) the sole or principle purpose of which is to protect the safety of life, health, or property;

(B) that are provided—

(i) by State or local government entities; or

(ii) by nongovernmental organizations that are authorized by a governmental entity whose primary mission is the provision of such services; and

(C) *that are not made commercially available to the public by the provider."*)

Wallop's Island, Fairbanks, and Greenbelt, InsideTrax™' asks that the Commission decline to adopt the unnecessarily restrictive rules advanced by ArrayComm, and instead adopt a more progressive rule based on the output power of the licensed service.

A. In Band Power Limits are Important to Interference Reduction

InsideTrax™ and AeroAstro have both urged the Commission adopt similar limits on power.[21] However, InsideTrax™ believes that the 1-watt peak output limit proposed by AeroAstro is unnecessarily restrictive, and reiterates its proposal that the Commission adopt a *peak* power limit of 4 watts in the 1670-1675 MHZ band. Power should be restricted to a maximum of 0.25 watts *average power* limit over a 60-second time interval. Using an average power standard would protect the situation where a number of mobile units might congregate such that their combined emissions would exceed the permissible out-of-band limit. Thus, over a 1-minute interval, the averaged transmitted power from any one mobile unit would be only 1/16 the peak power limit of 4 watts. Such a standard allows for maximum engineering efficiency and reuse potential.

Should the Commission adopt the disaggregation and partioning supported by other parties in this proceeding, these low in-band power and antenna limits are essential. Under such a licensing regime, a licensee could disaggregate its spectrum in such a way that, conceivably, part of it could be used for services with high power transmitters. Should such services use elevated adaptive beam forming antennas or similar technology, it will require substantially larger exclusion zones around protected government facilities than low power nondirectional devices. The Commission can prevent such future unintended consequences by adopting clear power limits in this proceeding.

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[21] *See* Comments of AeroAstro at 9.

B. Out of Band Interference Reduction

InsideTrax™ continues to recommend an adjacent band interference standard on any frequency outside of the authorized bandwidth of 55+10log(P) dB, where (P) is the highest emission in watts of the transmitter inside the authorized bandwidth. Such a standard will provide adequate protection measures for those operating outside of the 1670-1670 MHz band.

C. Protection to Radioastronomy Operations, Wallop's Island, VA, Fairbanks, AK, and Greenbelt, MD Facilities

InsideTrax™ has carefully assessed the technical rules outlined above to ensure that they will adequately protect operations of the incumbent facilities such as Wallop's Island, Virginia and Fairbanks, Alaska.[22] The proposed technical standards also require that operations would be sufficiently low in power that all likelihood of interference to radio astronomy operations in the subjacent 1660-1670 MHz band would be minimized.

InsideTrax™ also supported the Commission's proposed coordination and notification procedures regarding operation in the vicinity of the federal facilities at Greenbelt, Maryland.[23] In its earlier comments, InsideTrax™ noted that it did not believe that the proposed 65 km radius of protection proposed by the National Telecommunication and Information Administration was necessary. InsideTrax™ instead proposed that the radius of protection should take into account the nature of the transmitters, rather than setting a single limit for all in-band operations.

Attached to these Reply Comments is an extensive engineering study highlighting the fact that varying levels of power and types of operation can have a dramatic effect on the required exclusion zone.[24] While sixty five kilometers may be appropriate for a tower-mounted

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[22] *See* NPRM at para 122.
[23] *See* NPRM at paras. 130-135.
[24] *See* "Simulation for Zone of Exclusion Determination" (attached as w"Exhibit 1").

transmitter operating continuously at relatively high power, InsideTrax™' proposed service needs only 21 kilometers in its *worst-case scenario.*[25] Clearly, low power providers such as InsideTrax™ and AeroAstro should not be subject to unnecessarily expansive exclusion zones because other prospective application providers wish to use high power in their operations. Thus, InsideTrax™ 'asks that the Commission adopt a rule that accounts for the varying exclusion radii required by applications with differing power levels.

[25] *See* Exhibit 1 at 1 and Figure 3-7.

V. Conclusion

InsideTrax™ continues to endorse service and technical rules that will allow a broad range of potential licensees to provide valuable service to the public in the 1670-1675 MHz band. There should be a nationwide allocation of that band, licenses should be for a term of ten years, and the technical rules should be as flexible as possible while protecting incumbent federal operations.

Most importantly, however, InsideTrax™ asks the Commission to recognize the extraordinary utility of public safety bidding credits in allocating spectrum in the public interest. InsideTrax™ believes that it has clearly demonstrated the economic and social value of the externalities created by public safety applications and that the broader public interest will be served by accounting for those externalities in auctions. In light of these benefits -- and in the face of no real opposition -- the Commission should adopt such credits because they will serve the public interest for the many reasons already stated in this proceeding. By doing so, the Commission may ensure that the public interest is truly served in this reallocation proceeding.

Respectfully submitted,
INSIDETRAX™

By:
/s/ Mark Blacknell
Gregg P. Skall
Mark Blacknell
Counsel for InsideTrax™

Womble Carlyle Sandridge
& Rice, PLLC
1401 Eye Street, N.W., Seventh Floor
Washington, D.C. 20005
(202) 467-6900

March 18, 2002

Harris Corporation Private

Simulation for Zone of Exclusion Determination
for MicroTrax™ in the 1670-1675 MHz Band

Abstract:

MicroTrax is an emitter location system that relies on Time of Arrival (TOA) and Angle of Arrival (AOA) of transmitted RF bursts from radio "tags" to determine tag location. Depending on the characteristics and location of receivers for other services operating in the same frequency spectrum, there is the possibility of interference from the tag emissions.

This Technical Memo documents an effort to determine the required radius of an exclusion zone to protect the CDA ground station receivers located in Wallops Island, Virginia, and Fairbanks, Alaska, operating at a receive frequency of 1767 MHz.

The conclusions described in this TM are as follows:

- In **suburban** terrain, the required exclusion radius is **R_{min}=12 km**, for emission density = 2 transmissions per minute per square kilometer (the nominal system capacity) everywhere (see Figure 3-2).
- In **suburban** terrain, the required exclusion radius drops to **R_{min}=9 km** if the emission density is reduced ten-fold to 0.2 emissions per square km per minute (see Figure 2-5, compare to Figure 2-4). This exclusion radius decreases slightly to **R_{min}=8 km** if half of the coverage area is devoid of tags (because half of the coverage area is over the ocean) (see Figure 3-1).
- If the **emission density changes** from 0.02 for R<8 km to 0.2 for R>8 km, then the required exclusion zone radius is **R_{min}=8 km** (see Figure 3-5, compare to Figure 3-4).
- If we assume that **50%** of the coverage region is devoid of tags, and that the **emission density changes** from 0.02 to 2 for R>15 km, then the required exclusion zone for tags in suburban area has a radius **R_{min}=1 km.** Figure 3.6 shows the flux density for R_{min}=8 km, which is identical to the flux density for all smaller choices of R_{min}, since no additional emissions are added for the smaller R_{min} values at the 0.02 density value (see appendix B)
- If **open area terrain** is assumed, then the exclusion radius is **21 km** (the diffraction-limited range), for emission density = 2 everywhere and no water factor. Figure 3-7 shows that even one emitter at 21 km will violate the interference criterion, so the exclusion radius must be 21 km regardless of the emission density.
- Reflection of tag emissions from aircraft in the field-of-view of the CDA and emitters is much less than the energy received via the LOS Hata path loss.

1.0 Introduction

MicroTrax is a Harris-developed emitter location system that relies on Time of Arrival (TOA) of transmitted RF bursts from radio "tags" to determine tag location. Depending on the characteristics and location of receivers for other services operating in the same frequency spectrum, there is the possibility of interference from the tag emissions.

This Technical Memo documents an effort to determine the required radius of an exclusion zone to protect the GOES Command and Data Acquisition (CDA) stations located in Wallops Island, Virginia, and Fairbanks, Alaska, operating at 1767 MHz. The specified antenna gain for this terminal is 49 dBi, the specified receiver noise temperature is 50^o Kelvin (-182 dBW/kHz), and the antenna is pointed at the geosynchronous arc between 75^o W and 135^o W longitude. The criterion for protection of the CDA stations at Wallops Island and Fairbanks is as follows *[see Hurt, G.F., et al., Spectrum Reallocation Final Report, Response to Title VI – Omnibus Budget Reconciliation Act of 1993, NTIA Special Publication 95-32, February 1995, Appendix C, page C-2.*]:

- *The cumulative interference at the receiver input in any 1 kHz band can be no higher than 10 dB below the receiver thermal noise power in that band, for 99.99 percent of the time during any one-month period.*
- *The cumulative interference at the receiver input in any 1-Hz band can be no higher than the receiver thermal noise power in that band, for 99.99 percent of the time during any one-month period.*

Other parameters assumed for this analysis, unless noted otherwise, are as follows:

1. H_m = mobile (tag) height = 1.5 m
2. H_b = base (CDA station) height = 15 m
3. CDA station antenna sidelobe level in direction of tags (horizon) = 45 dB below peak of beam
4. Tag transmitter power = 1 Watt
5. Tag "enclosure" loss = 5 dB (due to being in a car or building, being body worn, etc.)
6. Diffraction range = 21 km = Tag Radio Horizon + CDA Radio Horizon, computed using $D_{\text{Radio Horizon (miles)}}$ = sqrt (2 H_{feet}) (based on 4/3 earth radius and H_b, H_m).
7. Tag transmit bandwidth = 4 MHz chirp
8. Chirps per burst = 10
9. Bursts per tag location operation = 4
10. Emission density = 2 [emissions/(km^2)/minute]

2.0 Analysis Model

The analysis model is based on the diagram shown in Figure 2-1. Radio tag emissions are assumed to occur at random within the annular rings with a density of r = 2/km^2/minute. Note that the number of tags per square km can be much larger than this value. Some tags may only transmit once or twice a day, while others may transmit much more frequently. For our purposes, all that matters is the spatial and temporal density r of tag emissions (i.e., transmissions) in the region surrounding the CDA earth station, located at the center of the concentric rings in Figure 2-1.

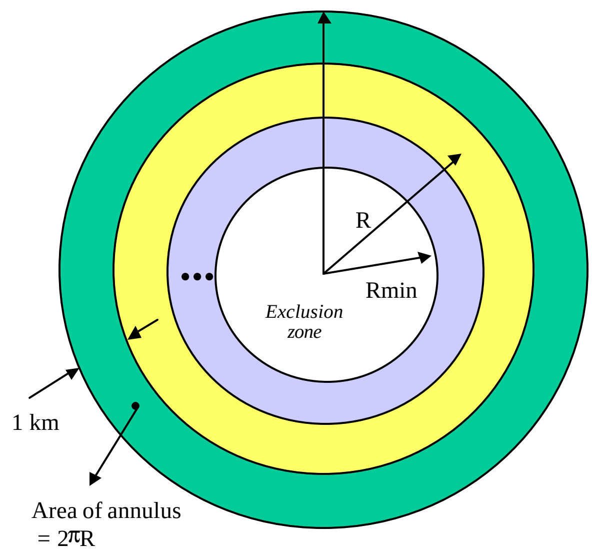


Figure 2-1 Annular Rings of Tag Emissions, With Exclusion Zone in Center

We assume that all tags in a ring at distance R suffer the same path loss, and the Hata path loss model is used to compute the median path loss for all tags in the ring at radius R [see Hata, M., IEEE Trans. VT Aug. 1980, pp. 371-325]. For our purposes, we assume that the width of each ring is 1 km.

Recall that the Hata path loss model has formulas for urban (large and medium/small city), suburban, and open area environments. We will use only the models for suburban and open area, with most of the effort devoted to the suburban path loss model. Path loss in nonLOS environments is characterized by a lognormal distribution, which means that the path loss measured in dB units has a normal (i.e., Gaussian) probability density function (i.e., is normally distributed). The commonly accepted value in the literature for the standard deviation of the lognormally distributed path loss is 6 to 8 dB. The Hata model is a median path loss model based on empirical formulas derived to fit large amounts of measured data. Path loss vs. range using the Hata model is shown in Figure 2-2 for three terrain types: small/medium city, suburban, and open area. Note that suburban path loss is approximately 20 dB larger than open area path loss.

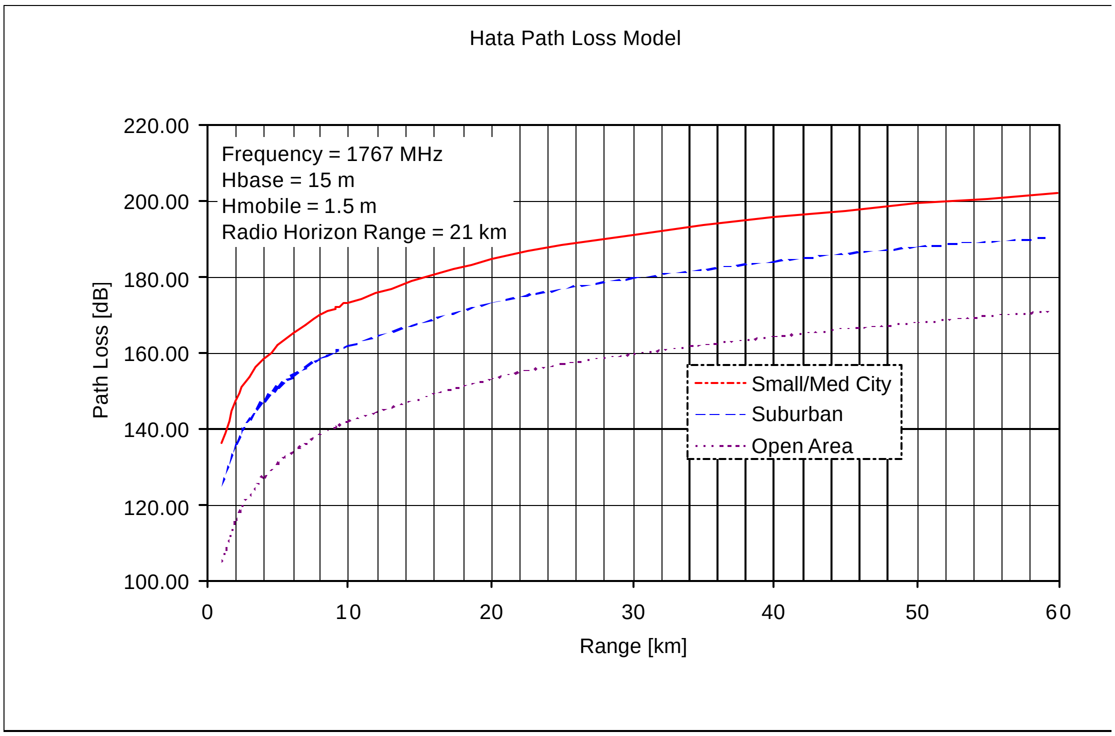


Figure 2-2 Hata Path Loss Model for City, Suburban, and Open Area Terrain

Since each ring has a width of 1 km, we compute the area of each ring as 2π R, where R is the radius to the center of the ring. The number of emissions from the k^{th} ring in a 1 minute interval is thus $N_e = \rho(2\pi R_k)$. The number of these transmissions from the k^{th} ring that overlap, and therefore add in power at the CDA receiver, is a binomially distributed random variable. The probability that there are exactly j simultaneous emissions at a given time instant is given by:

$$P_j = \binom{N_e}{j} p^j (1-p)^{(Ne-j)}$$

where the first factor (in parentheses) is the number of combinations of N_e things taken j at a time.

The probability p that a specific emission in the 1 minute interval is occurring at a given instant is given by:

p = (4 bursts)x(10 chirps/burst)x(8.192 msec/chirp)/((1000 msec/sec)x(60sec/minute))

p= 0.00546133

The flux density at the CDA station due to the k^{th} ring is computed by applying the path loss at range R_k to each emission from the k^{th} ring. The total flux density ? $_{Total}$ at the CDA station at any time instant is the sum of the flux densities contributed from each of the concentric rings, ? $_k$, ranging from R_{min} to R_{max}:

$$\Phi_{Total} = \sum_{R_{\min}}^{R_{\max}} \Phi_k$$

The flux density contributed from a specific ring is a random variable. Therefore, the total flux density at the CDA station is a sum of random variables. Since each ring has a different radius, the path loss from emissions in each ring is different.

In order to make probabilistic statements about total flux density, we must determine the probability density function (PDF) of the sum of random variables. The PDF of the sum of random variables is computed as the convolution of the individual PDF's. This convolution is usually performed by multiplying the Fourier transforms of the individual PDF's and then computing the inverse Fourier transform of the result. Since we are dealing with discrete PDF's with a different spacing for each ring, this implies a messy bookkeeping problem. Therefore, a MATLAB simulation was used to obtain the result instead.

The simulation is structured as follows. For each (k^{th}) ring, a binominally distributed random variable is created to represent the number of simultaneous emissions from that ring. The Hata path loss corresponding to distance R_k is computed and applied to the tag emissions from the k^{th} ring. The flux density at the CDA station contributed by each of the rings is summed over the range R_{min} to R_{max}, where R_{max} is the diffraction-limited range and R_{min} is a loop variable. The value of the diffraction-limited range R_{max} is such that the line-of-sight (LOS) path from a tag to the CDA station just grazes the earth. Distances larger than this value suffer very large diffraction losses, and for our purposes are of no consequence. R_{min} is in a loop so that we may ascertain from the simulation which value of R_{min} allows the interference threshold requirement to be met. The result of the simulation at this point is a single plot that shows total flux ? $_{total}$ vs. R_{min} for the particular set of random emissions that was simulated. This whole process is then repeated a large number of times (typically 10,000) and histograms showing the PDF of flux density values for each choice of R_{min} are generated.

Figure 2-3 shows the superposition of 10,000 plots of total flux density vs. R_{min}, along with the required threshold value, -192 dBW/kHz. There is a PDF of flux density values for each value of R_{min} in this figure. It appears from Figure 2-3 that R_{min}=8 km ensures that the threshold value will not be exceeded. A histogram based on at least 10,000 trials (and preferably several times that many) is required to make assertions at the 99.99% confidence level. The smallest R_{min} value that meets the interference threshold requirement (i.e., flux density of –192 dBW/kHz at CDA not exceeded more than 0.01% of the time) is defined as the exclusion zone radius. The histogram for R_{min}=8 and 10,000 trials is shown in Figure 2-4. This figure shows that for R_{min}=8 km, the -192 dBW/kHz threshold is equaled or exceeded *very slightly* more than 0.01% of the time, which is the criterion for choosing the radius of the exclusion zone. Figure 2-5 shows that for R_{min}=9 km, the interference criterion is easily met.

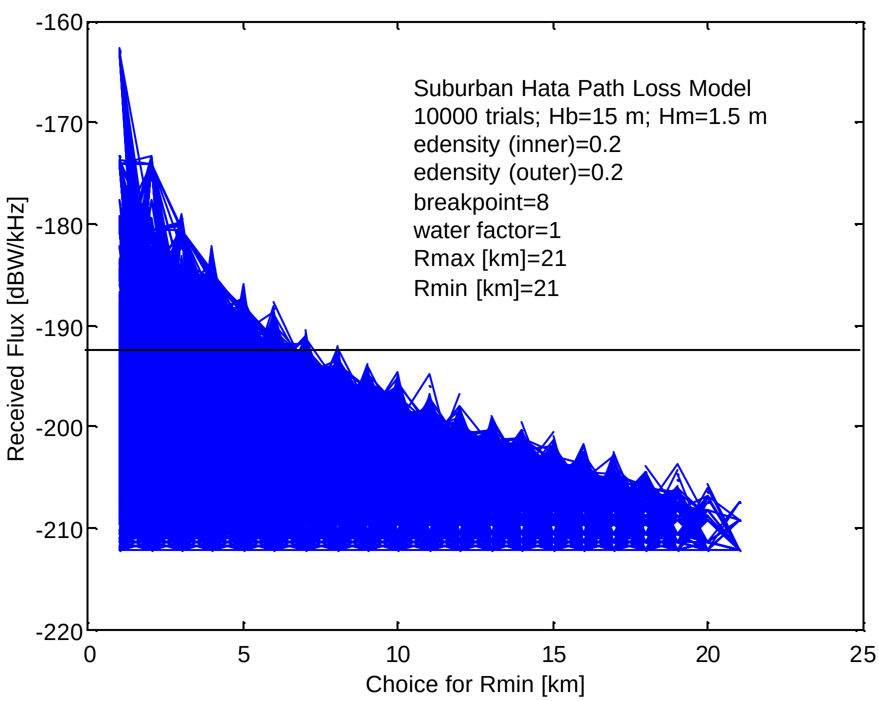


Figure 2-3 Flux Density vs. R_{min}

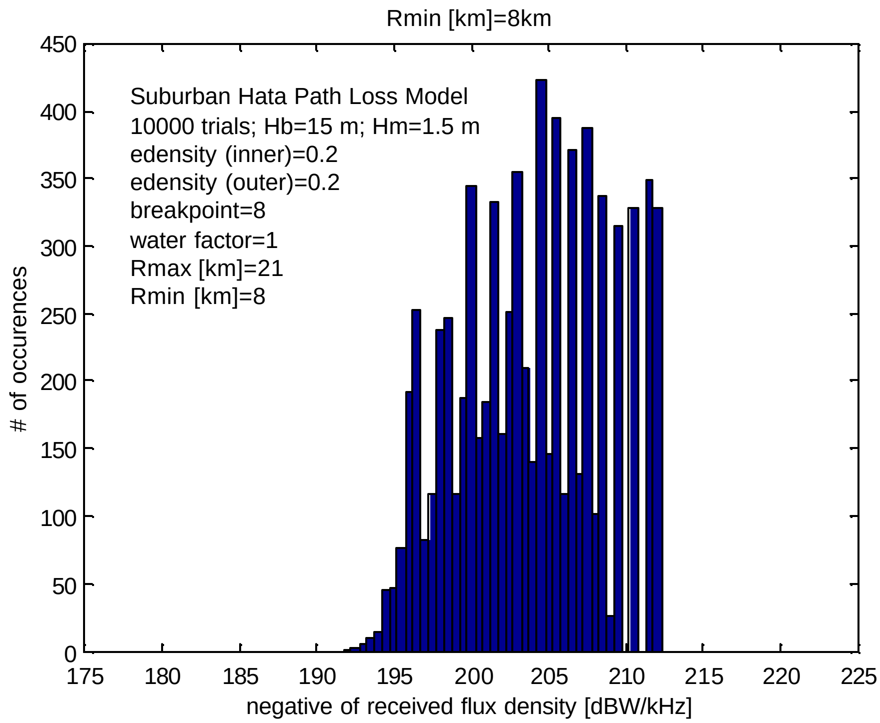


Figure 2-4 Histogram of CDA Flux Density for R_{min} =8 km, Suburban Path

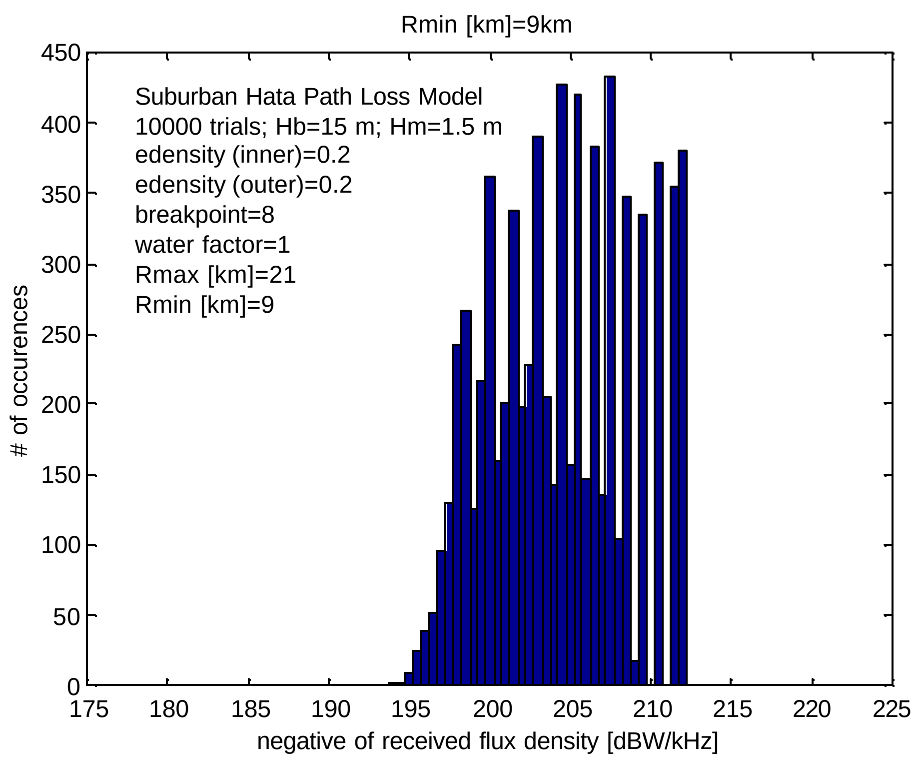


Figure 2-5 Histogram of CDA Flux Density for R_{min} =9 km, Suburban Path

The conclusion from the above results is that the radius of the exclusion zone must be 9 km or greater in suburban terrain in order to unequivocally meet the threshold requirement. It will be shown later that the worst case exclusion zone radius increases to 12 km if the emission density is increased ten-fold to 2, which is the maximum value that the MicroTrax system can support.

3.0 Other Simulation Results

There are some variations of this problem that can be investigated, once the basic MATLAB simulation is available. For example, one can postulate that some specified fraction of the coverage area will not have any tags in it due to the fact that the specified fraction of the area consists of marsh, dense woods, or water (ocean perhaps). The resulting reduction in CDA flux density moves the histograms appropriately to the right (i.e., lower flux density at the CDA). The magnitude of "appropriately lower" is not obvious, however.

For example, if the water coverage fraction is 50%, then the number of emissions per ring is cut in half (approximately, depending on bias effects which are described in Appendix B). However, the flux density is not a linear function of the number of emissions per ring. Flux density depends not only on the number of emissions in each ring and the number of rings, but also on the degree to which the emissions are coincident in time. The number of time-coincident emissions from each ring is a binomially distributed random variable, and the path loss from each ring is a nonlinear function of ring radius. We must rely on simulation to see how flux density varies with water coverage. It is not simply a matter of sliding the histogram to the right by 3 dB for 50% water coverage.

This is illustrated by comparing Figures 2-4 with Figure 3-1 below. The parameters for these two figures are identical except that Figure 3-1 assumes that 50% of the area of each ring is devoid of emissions (due to proximity of the ocean, for example). Recall that the result in Figure 2-4 (R_{min}=8 km) just barely missed meeting the interference requirement. Note that the overall range, shape, and left-hand tail of the histogram in the two figures are similar. However, there is a smoother distribution of outcome probabilities for the no-water case (Figures 2-4), for which there are more emissions per ring, and therefore a correspondingly richer combinatorial space. The key result of this comparison, however, is that the flux density histogram in Figure 3-1 is very nearly the same as in the no-water case of Figure 2-4. This is not a generalizable result. For some parameter value sets of this problem, the presence of water in the coverage area does significantly decrease the flux density.

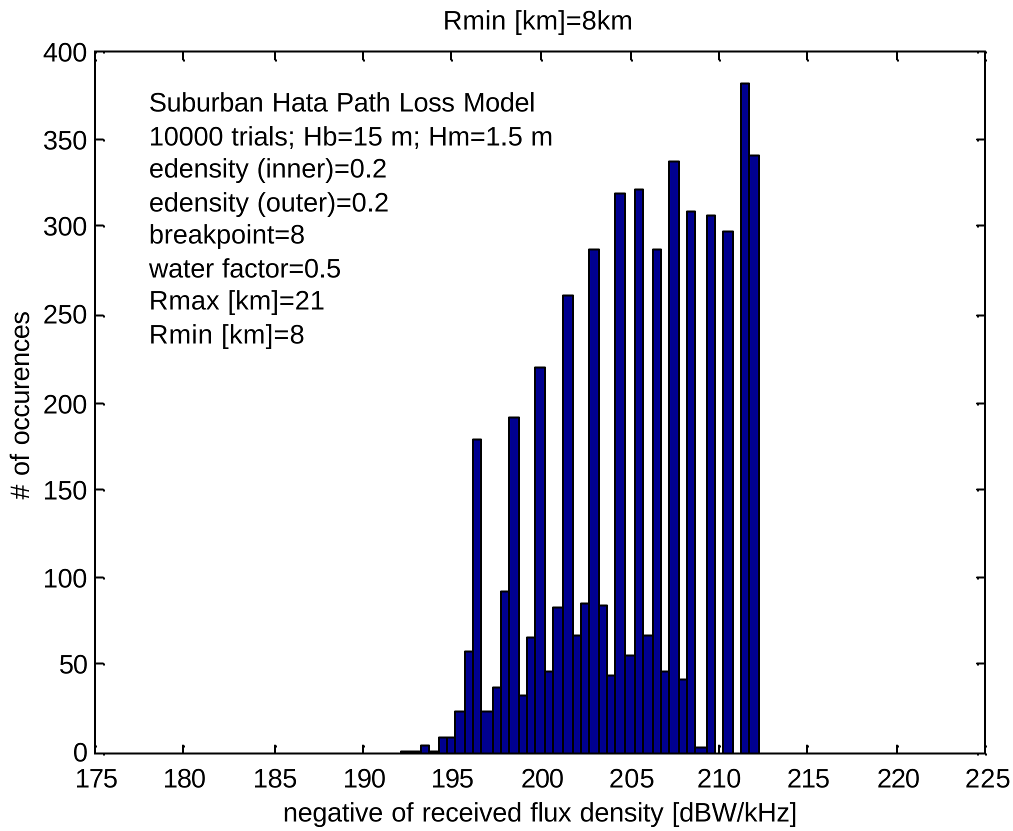


Figure 3-1 Flux Density for R_{min} =8 km, Suburban Path (1/2 of coverage over ocean)

In contrast to the above concept, scaling (sliding) of histogram results *is* appropriate if we change the tag transmit power, the tag enclosure loss, or the CDA sidelobe level. This is because for these types of changes, the *number* of emissions remains constant, and the flux density at the CDA scales dB-for-dB with changes in the aforementioned parameters.

Changes in other parameter values require that the simulation be run again. For example, the path length to the radio horizon is a nonlinear (i.e., square root) function of the antenna heights, and the path loss is a highly nonlinear function of antenna heights and path length.

Worst-Case Exclusion Zone Radius

The maximum capacity for the MicroTrax system is approximately 2 emissions per square km per minute. Figure 3-2 shows that the corresponding worst-case required exclusion zone radius is 12 km for suburban propagation environments. This figure assumes the maximum MicroTrax system capacity of 2 emissions per square km per minute and full area coverage of each ring (i.e., no water in coverage area). Recall that the required exclusion radius (R_{min}) was 8 km for an emission density of 0.2 emissions per square km per minute. Thus, a ten-fold increase in emission density increases the exclusion zone radius from 8 km to 12 km.

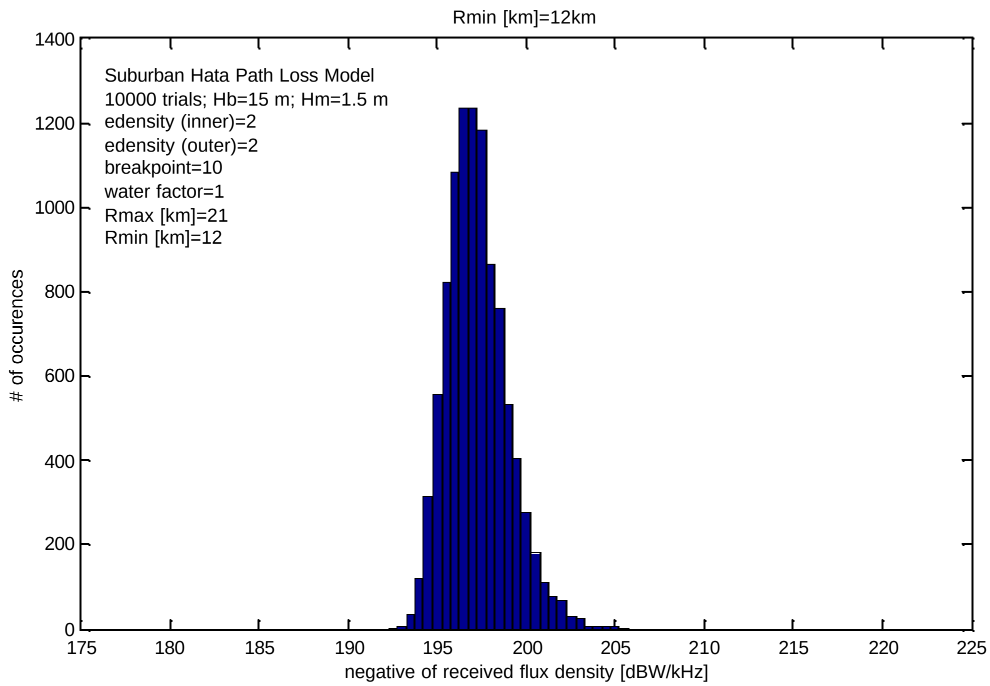


Figure 3-2 Worst-case Required Exclusion Radius is 12 km, Surburban Path

Buffer Zone Concept

Another interesting variation of the problem is to assume two different emission density values, depending on radius, as illustrated in Figure 3-3. In this figure, the tags are assigned for use in the deployment zone. However, a buffer zone is defined such that if some of the tags stray out of the deployment zone into the buffer zone, the CDA interference criterion is still met. For our purposes, it was assumed that the tag emission density r_{outer} = 0.2 [emissions/(km^2)/minute] in the deployment zone and r_{inner} = 0.02

[emissions/(km^2)/minute] in the buffer zone. As before, the tag emission density is zero in the exclusion zone.

Buffer Zone Concept

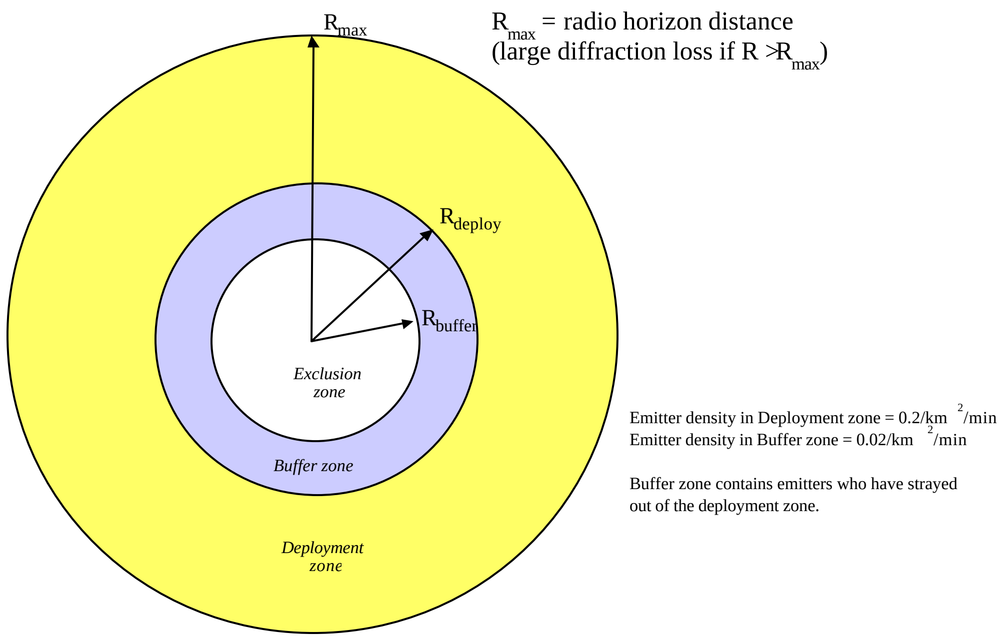


Figure 3-3 Buffer Zone vs. Deployment Zone Concept

Another assumption we make concerns the fraction of the area that is devoid of emitters or tags (hereafter referred to as the "water factor", since tags are unlike to be deployed on the ocean).

We can independently choose among these variations of the assumptions (emission density and water factor). The following figures show some simulation results for various choices. Figure 3.4 shows that choosing R_{min}=7 km for the case in which the emission density changes from 0.02 to 0.2 at 8 km does not meet the interference criterion. The next figure (Figure 3-5) shows that increasing the value of R_{min} to 8 km does permit the interference requirement to be met. However, since the breakpoint is also at 8 km, this is the same as having emission density = 0.2 everywhere and choosing R_{min}=8 km.

If the breakpoint is selected as 15 km and the density changes from 0.02 to 2 (the maximum value supportable by the system) at the breakpoint, and half of the coverage is over the ocean, the result is that the interference requirement can be met for *any* choice of R_{min}. The reason is not obvious at first glance. Referring to appendix B, table B2, we see that for water factor times emission density = 0.01, the number of computed emissions per ring is (rounded to) zero until R = 8 km and equal to 1 thereafter. Of course, the number of emissions jumps at the breakpoint (15 km) to a much higher value, but these emissions are at such a large distance they do not contribute much to the density at the CDA. Figure 3.6 shows the flux density for R_{min}=8 km. Smaller choices for R_{min} do not change the flux density because no additional emissions are included for R_{min} choices smaller than 8 km.

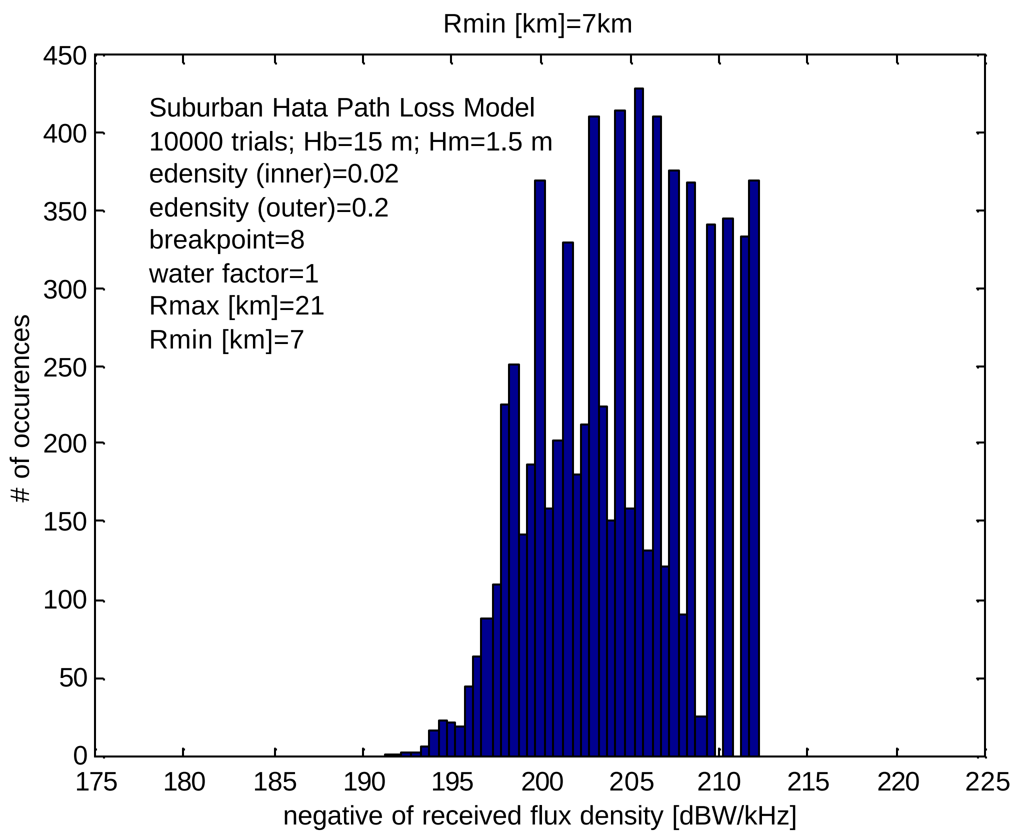


Figure 3-4 Flux Density For Emission Density Breakpoint at 8 km; R_{min}=7 km

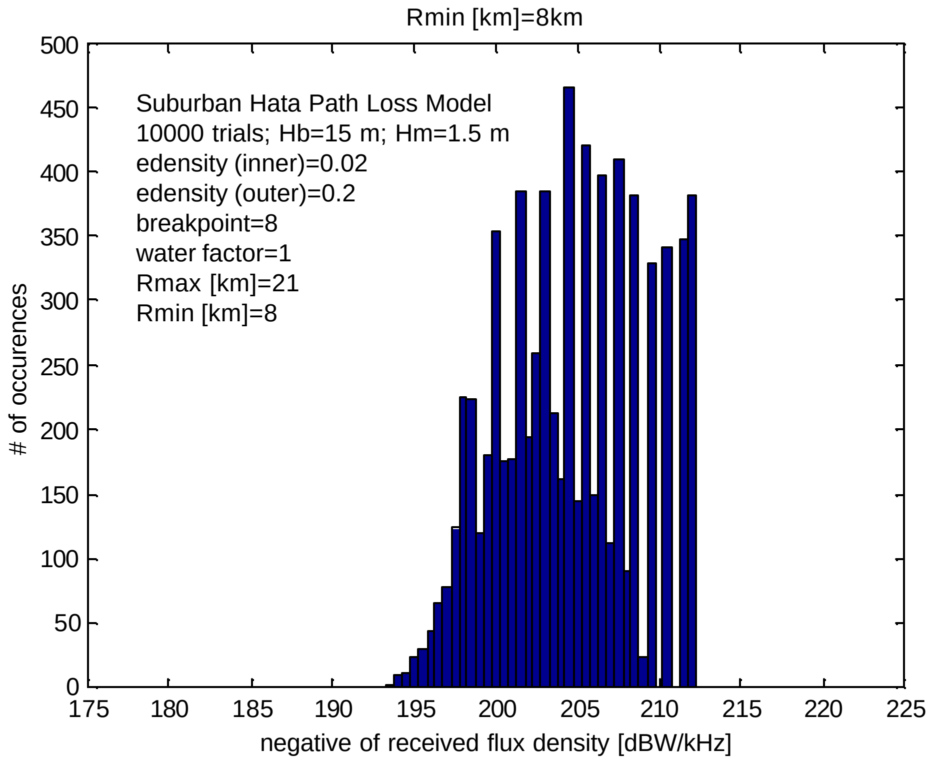


Figure 3-5 Flux Density For Emission Density Breakpoint at 8 km; R_{min}=8 km

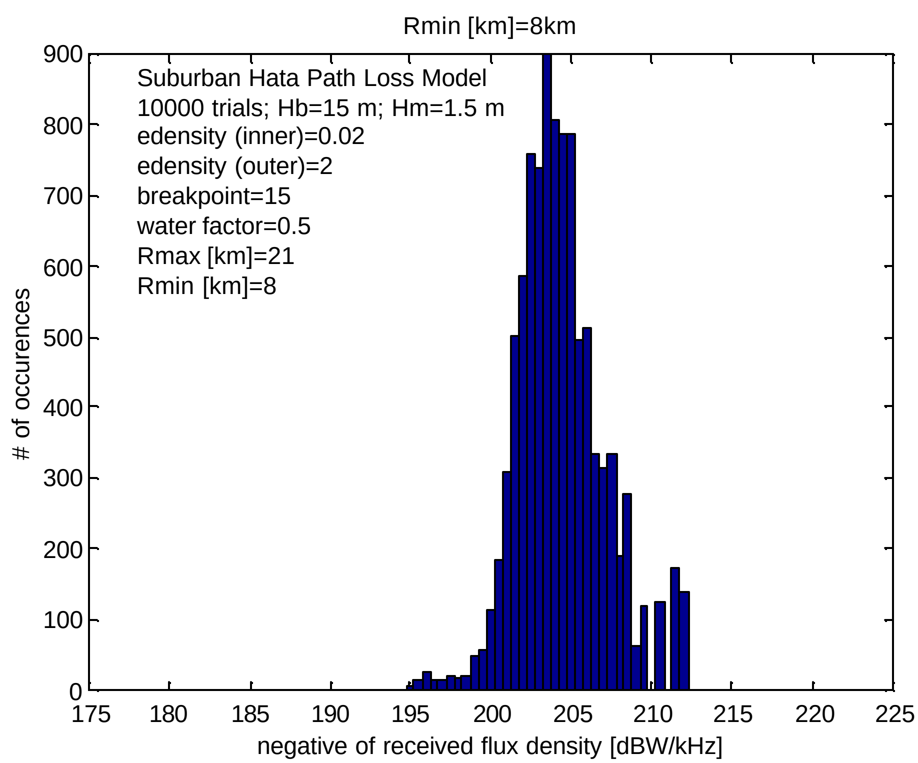


Figure 3-6 Flux Density For Emission Density Breakpoint at 15 km; R_{min}=8 km

Open Terrain

Figure 3-7 shows that even if we restrict emissions to the outermost ring at R_{min} = 21 km (the diffraction-limited maximum path length for the assumed antenna heights), the interference threshold criterion cannot be met for open area terrain and emission density of 0.2. This is because the path loss over open terrain is about 20 dB less than over suburban terrain. Note from the figure that in 10,000 trials, there were less than 1300 events, i.e., occurrences of one or more emissions for a given time instant. Most (less than 1200) of these events were single emissions, (-192 dBW/kHz flux density). There were less than 100 events corresponding to two simultaneous emissions (-192+10*LOG(3) =-189 dBW/kHz flux density), and a single occurrence of three simultaneous emissions emissions (-192+10*LOG(3) =-187.2 dBW/kHz flux density).

Figure 3-8 shows the distribution of flux density for R_{min}=17 km over open area terrain. As expected, there are more events and the center of the distribution has moved to higher flux density levels (to the left in the figure).

Figure 3-9 shows the distribution of flux density for R_{min}=17 km over open area terrain but with a ten-fold increase in emission density, to 2 emissions per square km per minute. There are many more simultaneous emissions and the center of the distribution has moved to even higher flux density levels (to the left in the figure – note change in abscissa scale).

Assuming an open area environment is probably not appropriate. It is unlikely that a circular area of 21 km radius centered at the CDA on Wallops Island will be “open” or treeless, except, obviously, for the portion of the area over the ocean. An examination of aerial photographs of the region surrounding the CDA shows a large number of small, cultivated fields edged with narrow strips of woods, with some marshland close-in to the CDA. For this reason, the suburban (presumably partially wooded) Hata model was used for most of the simulations reported in this TM

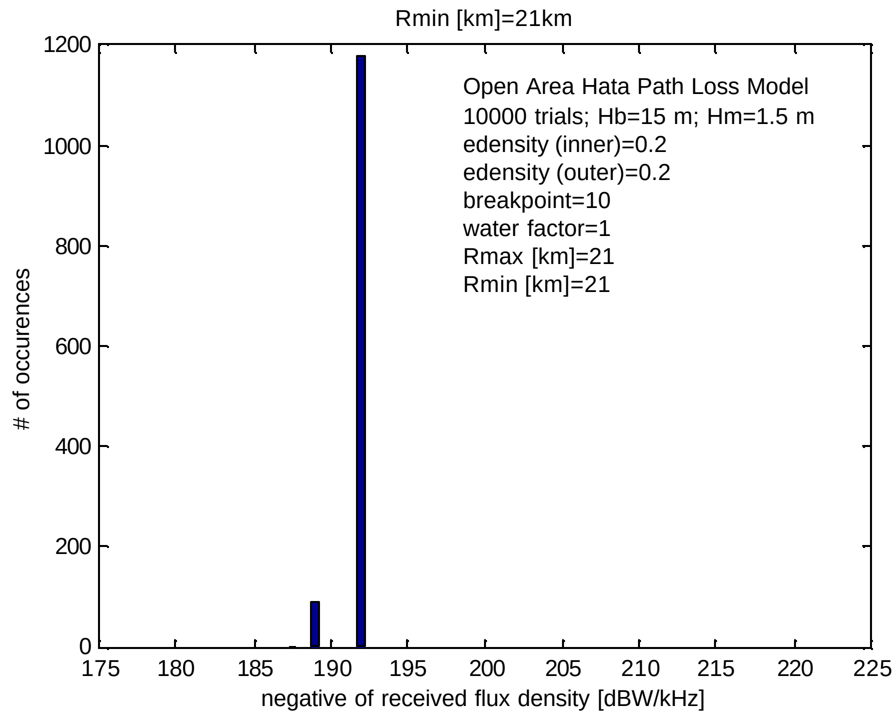


Figure 3-7 Flux Density for R_{min} = 21 km (open terrain) & r = 0.2

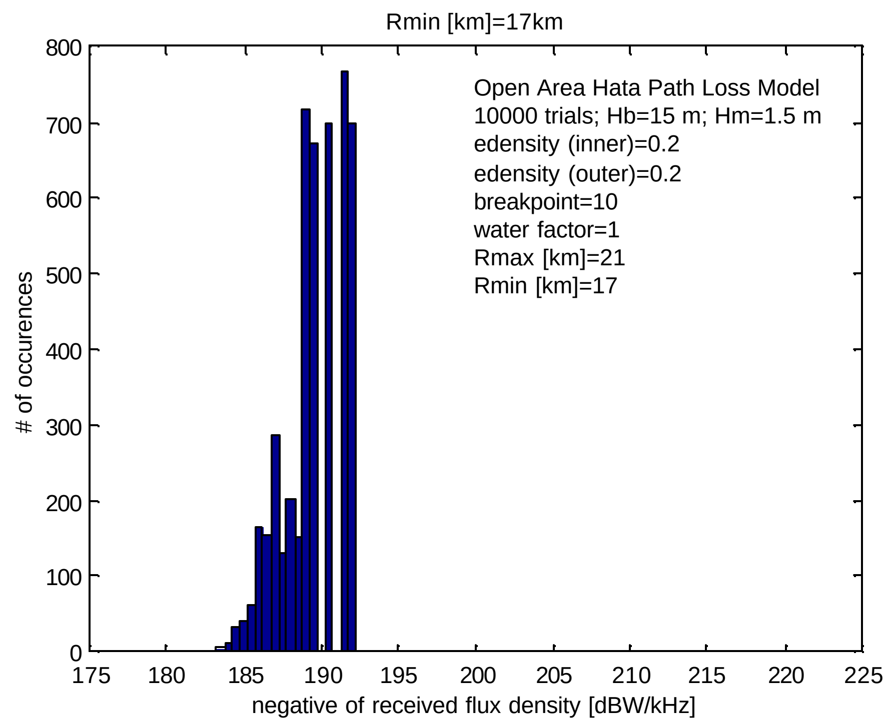


Figure 3-8 Flux Density for R_{min} = 17 km (open terrain) & r = 0.2

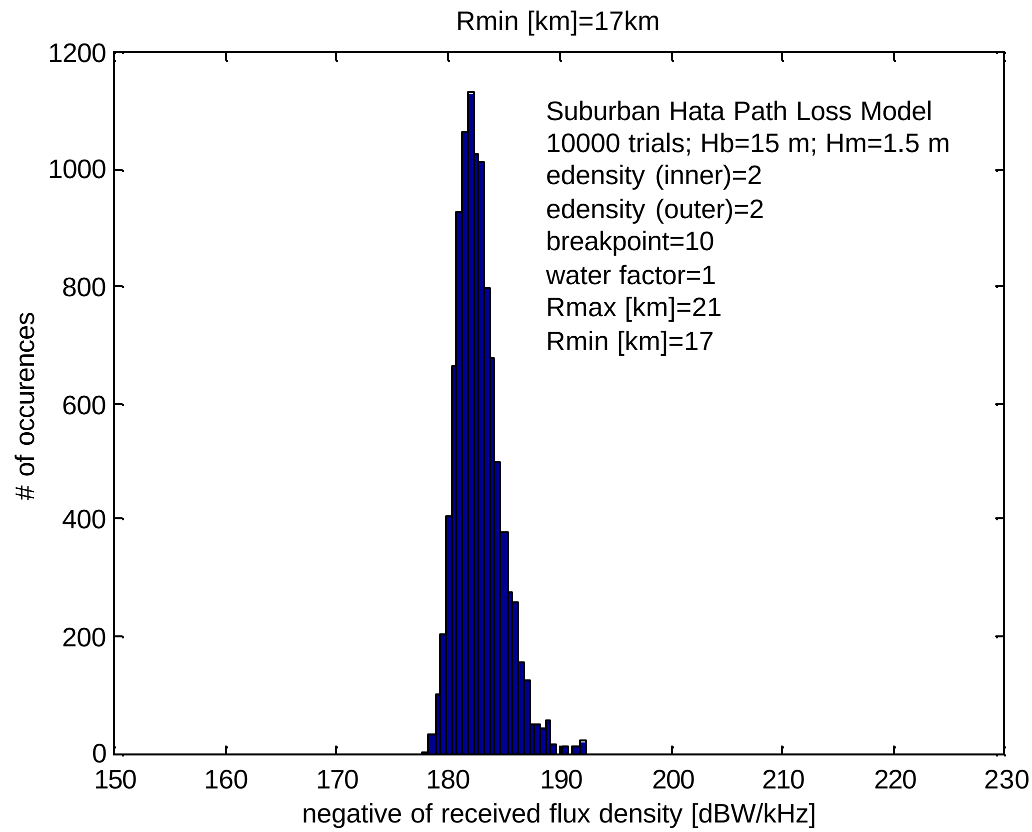


Figure 3-9 Flux Density for R_{min} = 17 km (open terrain) & r = 2

4.0 Conclusions

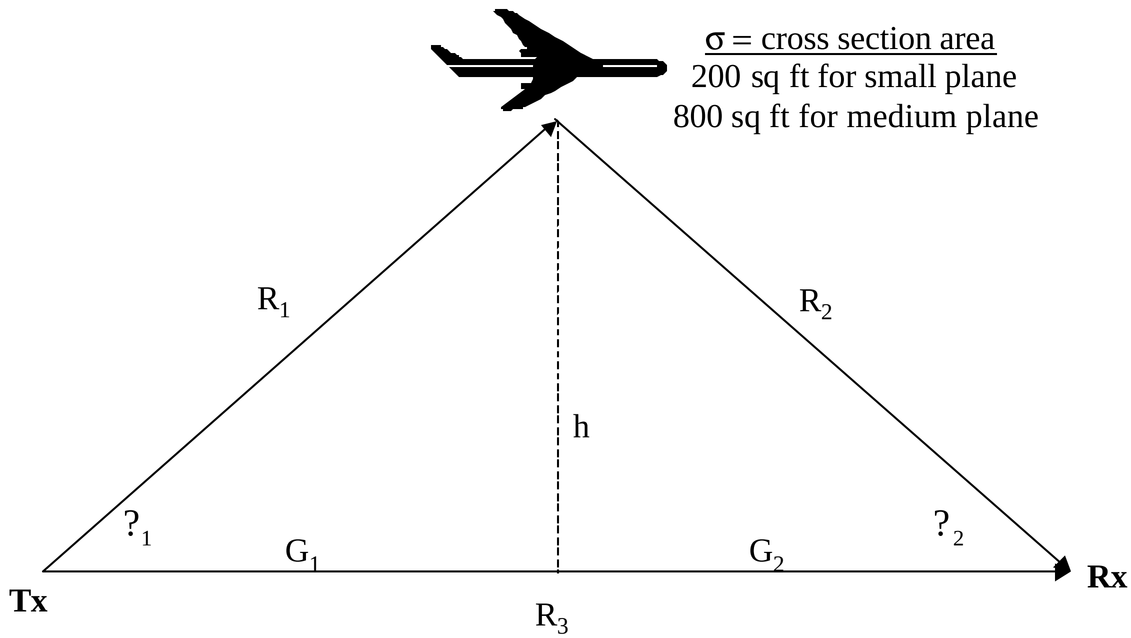
A useful MATLAB program has been developed for simulating the interference flux density at a GOES CDA station that results from a multitude of MicroTrax™ tag transmitters. The objective of the simulation is to determine the value of the radius of the exclusion zone that ensures that the interference level at the CDA station does not exceed the specified level more often than is permitted (0.01% of the time). The Hata model was used to compute median path loss, and the terrain type can be specified by the user to be suburban, open area. The user can specify what fraction of the coverage area is devoid of tags (due to presence of water or marshlands, for example). The user can change the emission density at a user-specified radius.

The following conclusions are based on the simulation and analysis results.

- In **suburban** terrain, the required exclusion radius is **R_{min}=12 km**, for emission density = 2 (the maximum permissible value) everywhere (see Figure 3-2).
- In **suburban** terrain, the required exclusion radius drops to **R_{min}=9 km** if the emission density is reduced ten-fold to 0.2 emissions per square km per minute (see Figure 2-5, compare to Figure 2-4). This exclusion radius decreases slightly to **R_{min}=8 km** if half of the coverage area is devoid of tags (because half of the coverage area is over the ocean) (see Figure 3-1).
- If the **emission density changes** from 0.02 to 0.2 for R>8 km, then the required exclusion zone radius is **R_{min}=8 km** (see Figure 3-5, compare to Figure 3-4).
- If we assume that **50%** of the coverage region is devoid of tags, and that the **emission density changes** from 0.02 to 2 for R>15 km, then the required exclusion zone radius for **suburban** conditions is **R_{min}=1 km.** Figure 3.6 shows the flux density for R_{min}=8 km, which is identical to the flux density for all smaller choices of R_{min}, since no additional emissions are added for the smaller R_{min} values at the 0.02 density value (see appendix B)
- If **open area terrain** is assumed, then the exclusion radius is **21 km** (the diffraction-limited range), for emission density = 2 everywhere and no water factor. Figure 3-7 shows that even one emitter at 21 km violates the interference criterion, so the exclusion radius must be 21 km regardless of the emission density.
- Reflection of tag emissions from aircraft in the field-of-view of the CDA and emitters is much less than the energy received via the LOS Hata path loss.

Appendix A : Reflection of Tag Emissions from Airplanes

One potential concern is the possibility of RF power from a tag emission being reflected from a passing airplane into the CDA and causing interference. This problem was analyzed according to the model in Figure A-1.



Reflected path loss [dB] = 103.4 + 20*LOG($R_{1(km)}R_{2(km)}F_{MHz}$) - 10*LOG(σ)
Use Hata Model for the direct path along R_3 = R_1Cos(?$_1$)R_2Cos(?$_2$)

Figure A-1 Plane Reflection Geometry

The loss via the plane reflection path (R_1 and R_2) was computed for a small plane and a medium plane and compared to the path loss via R_3 based on the Hata model [see Hata, M., IEEE Trans. VT Aug. 1980, pp. 371-325]. In all cases, the loss is defined as the loss between an isotropic transmitting antenna and an isotropic receiving antenna. The tabulated results are shown in Tables A-1, A-2, and A-3, respectively. The values for the cross section area for a small and medium plane were taken from Table 1, page 6 of Chapter 29 of Reference Data for Radio Engineers, 5th Edition, Howard W. Sams & Co, Subsidiary of ITT.

The formula for the path loss via the plane reflection path is:

$$L\,[dB] = 103.4 + 20LOG_{10}\left(R_{1_{km}} R_{2_{km}} F_{MHz}\right) - 10LOG_{10}(s)\ [dB].$$

This formula was derived as follows. The flux density at the aircraft due to an isotropic radiator at the ground transmitter is simply the transmit power divided by the surface area of a sphere of radius R_1:

$$\Phi_{plane} = \frac{P_{TX}}{4pR_1^{\ 2}} \text{ [Watts/meter}^2\text{]}$$

The flux density at an isotropic antenna at the ground receiver is the product of the flux density at the plane, the effective cross section area of the plane, and the path (i.e., spreading) loss from the plane to the receiver.

$$\Phi_{RX} = \left(\frac{P_{TX}}{4pR_1^{\ 2}}\right)\cdot(s)\cdot\left(\frac{1}{4pR_2^{\ 2}}\right) \text{ [Watts/meter}^2\text{].}$$

Multiplying this received flux density by the effective area of an isotropic antenna (?^{2}/4p) yields the power received by an isotropic antenna at the ground receiver.

$$P_{RX} = \left(\frac{P_{TX}}{4pR_1^{\ 2}}\right)\cdot(s)\cdot\left(\frac{1}{4pR_2^{\ 2}}\right)\cdot\left(\frac{l^2}{4p}\right) \text{ [Watts].}$$

The path *gain* is the ratio of received power to transmitted power:

$$PathGain\ G_{path} = \frac{P_{RX}}{P_{TX}} = \left(\frac{1}{4p}\right)^3\cdot\left(\frac{l^2 s}{R_1^{\ 2} R_2^{\ 2}}\right)$$

Replace ? with *c*/F, where *c*=300x10^6 m/s is the speed of light and F is frequency in Hz, and convert F to F_{MHZ}, frequency in MHz. Convert the ranges R_1 and R_2 in meters to ranges in kilometers. The result is:

$$PathGain\ G_{path} = \frac{P_{RX}}{P_{TX}} = \left(\frac{1}{4p}\right)^3\cdot\left(\frac{\left(\frac{300\cdot 10^6}{F_{MHz}\cdot 10^6}\right)^2 s}{\left(R_{1km}\cdot 10^3\right)^2\left(R_{2km}\cdot 10^3\right)^2}\right)$$

Taking the logarithm of this expression to convert it to units of dB, and reversing the sign of each resulting term to give path *loss* in (positive) dB's yields the desired result:

$$L[dB] = 103.4 + 20LOG_{10}\left(R_{1_{km}} R_{2_{km}} F_{MHz}\right) - 10LOG_{10}(s)\ [dB]$$

Table A-1 Path Loss via Reflection From a Small Plane (area = 200 sq. ft.)

1767 = Freq [MHz]
18.59 =plane cross-section [m^2] **(200 square feet = small plane)**

Ground Range [km]	*Reflected Path Loss [dB] with altitude [km] as a parameter*									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	210.52	214.61	218.82	222.56	225.79	228.59	231.03	233.19	235.13	236.88
2	221.15	222.56	224.50	226.65	228.80	230.86	232.80	234.61	236.28	237.83
3	227.91	228.59	229.61	230.86	232.25	233.69	235.13	236.54	237.91	239.22
4	232.80	233.19	233.81	234.61	235.53	236.54	237.61	238.69	239.77	240.84
5	236.63	236.88	237.29	237.83	238.48	239.22	240.01	240.84	241.70	242.56
6	239.77	239.95	240.24	240.63	241.10	241.65	242.26	242.91	243.59	244.29
7	242.43	242.56	242.78	243.07	243.43	243.85	244.33	244.84	245.39	245.97
8	244.74	244.84	245.01	245.24	245.52	245.85	246.23	246.65	247.10	247.57
9	246.78	246.86	246.99	247.17	247.40	247.67	247.98	248.32	248.69	249.09
10	248.61	248.67	248.78	248.93	249.11	249.33	249.59	249.87	250.19	250.52
11	250.26	250.31	250.40	250.52	250.68	250.86	251.08	251.32	251.59	251.87
12	251.77	251.81	251.89	251.99	252.12	252.28	252.46	252.67	252.90	253.14
13	253.16	253.19	253.26	253.35	253.46	253.59	253.75	253.93	254.13	254.34
14	254.44	254.47	254.53	254.61	254.70	254.82	254.96	255.11	255.28	255.47
15	255.64	255.67	255.72	255.78	255.87	255.97	256.09	256.23	256.38	256.54
16	256.76	256.78	256.83	256.88	256.96	257.05	257.16	257.28	257.41	257.56
17	257.81	257.83	257.87	257.92	257.99	258.07	258.16	258.27	258.39	258.52
18	258.80	258.82	258.86	258.90	258.96	259.03	259.12	259.22	259.32	259.44
19	259.74	259.76	259.79	259.83	259.88	259.95	260.03	260.11	260.21	260.32
20	260.63	260.65	260.68	260.71	260.76	260.82	260.89	260.97	261.06	261.15
21	261.48	261.49	261.52	261.55	261.60	261.65	261.71	261.78	261.86	261.95
22	262.29	262.30	262.32	262.35	262.39	262.44	262.50	262.56	262.64	262.72
23	263.06	263.07	263.09	263.12	263.16	263.20	263.25	263.31	263.38	263.46
24	263.80	263.81	263.83	263.85	263.89	263.93	263.98	264.03	264.09	264.16
25	264.51	264.52	264.53	264.56	264.59	264.63	264.67	264.72	264.78	264.84

Note: R_1=R_2 for results in this table

Table A-2 Path Loss via Reflection From a Medium Plane (area = 800 sq. ft.)

1767 = Freq [MHz]
74.36 =plane cross-section [m^2] **(800 square feet = medium plane)**

Ground Range [km]	*Reflected Path Loss [dB] with altitude [km] as a parameter*									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	204.50	208.59	212.80	216.54	219.77	222.56	225.01	227.17	229.11	230.86
2	215.13	216.54	218.48	220.63	222.78	224.84	226.78	228.59	230.26	231.81
3	221.89	222.56	223.59	224.84	226.23	227.67	229.11	230.52	231.89	233.19
4	226.78	227.17	227.79	228.59	229.51	230.52	231.59	232.67	233.75	234.82
5	230.61	230.86	231.27	231.81	232.46	233.19	233.99	234.82	235.68	236.54
6	233.75	233.93	234.22	234.61	235.08	235.63	236.23	236.88	237.57	238.27
7	236.41	236.54	236.76	237.05	237.41	237.83	238.31	238.82	239.37	239.95
8	238.72	238.82	238.99	239.22	239.50	239.83	240.21	240.63	241.08	241.55
9	240.76	240.84	240.97	241.15	241.38	241.65	241.96	242.30	242.67	243.07
10	242.59	242.65	242.76	242.91	243.09	243.31	243.57	243.85	244.17	244.50
11	244.24	244.29	244.38	244.50	244.66	244.84	245.06	245.30	245.56	245.85
12	245.75	245.79	245.87	245.97	246.10	246.26	246.44	246.65	246.87	247.12
13	247.14	247.17	247.24	247.33	247.44	247.57	247.73	247.91	248.11	248.32
14	248.42	248.45	248.51	248.59	248.68	248.80	248.94	249.09	249.26	249.45
15	249.62	249.65	249.69	249.76	249.85	249.95	250.07	250.21	250.36	250.52
16	250.74	250.76	250.81	250.86	250.94	251.03	251.14	251.26	251.39	251.54
17	251.79	251.81	251.85	251.90	251.97	252.05	252.14	252.25	252.37	252.50
18	252.78	252.80	252.84	252.88	252.94	253.01	253.10	253.19	253.30	253.42
19	253.72	253.74	253.77	253.81	253.86	253.93	254.00	254.09	254.19	254.30
20	254.61	254.63	254.65	254.69	254.74	254.80	254.87	254.95	255.04	255.13
21	255.46	255.47	255.50	255.53	255.58	255.63	255.69	255.76	255.84	255.93
22	256.27	256.28	256.30	256.33	256.37	256.42	256.48	256.54	256.62	256.70
23	257.04	257.05	257.07	257.10	257.14	257.18	257.23	257.29	257.36	257.44
24	257.78	257.79	257.81	257.83	257.87	257.91	257.96	258.01	258.07	258.14
25	258.49	258.50	258.51	258.54	258.57	258.61	258.65	258.70	258.76	258.82

Note: R_1=R_2 for results in this table

Table A-3 Path Loss via Ground Path (Hata Model)

	Hata Model Path Loss [dB]				Free
range [km]	Large City*	Small/Med City	Suburban	Open Area	Space [dB]
1	137.64	137.60	125.93	106.07	96.99
2	148.84	148.80	137.13	117.27	103.01
3	155.39	155.35	143.68	123.82	106.53
4	160.04	160.00	148.32	128.47	109.03
5	163.64	163.60	151.93	132.07	110.96
6	166.59	166.55	154.87	135.02	112.55
7	169.08	169.04	157.36	137.51	113.89
8	171.24	171.20	159.52	139.66	115.05
9	173.14	173.10	161.42	141.57	116.07
10	174.84	174.80	163.12	143.27	116.99
11	176.38	176.34	164.66	144.81	117.81
12	177.79	177.75	166.07	146.21	118.57
13	179.08	179.04	167.36	147.51	119.26
14	180.28	180.24	168.56	148.70	119.91
15	181.39	181.35	169.67	149.82	120.51
16	182.43	182.39	170.72	150.86	121.07
17	183.41	183.37	171.70	151.84	121.59
18	184.34	184.30	172.62	152.76	122.09
19	185.21	185.17	173.49	153.64	122.56
20	186.04	186.00	174.32	154.47	123.01
21	186.83	186.79	175.11	155.25	123.43
22	187.58	187.54	175.86	156.01	123.83
23	188.30	188.25	176.58	156.72	124.22
24	188.98	188.94	177.27	157.41	124.59
25	189.64	189.60	177.93	158.07	124.94

Input Data

1676 = frequency [MHz]
15 = base ant height [m]
1.5 = mobile ant height [m]
13.06 = 2-antenna radio horizon [miles]
21.01 = 2-antenna radio horizon [km]

In comparing the direct path loss (Hata model) for various terrain types with the reflected path loss, we see that the *reflected path loss is orders of magnitude larger than the direct path loss* for both the small and medium plane cross section area assumption. Even if we increase the cross section area by several orders of magnitude (very large plane assumption), the direct path provides the least loss and the strongest signal.

If the plane happens to be in the main beam of the CDA, then the received power goes up by 45 dB (for our assumptions). However, if an aircraft *is equally likely to be* *anywhere in the hemispherical field of view*, the probability that it is in the main beam is given by the ratio of solid angle of the beam {(2p(1-cos(?$_{3dB}$/2)} to the solid angle of a hemisphere (2p). For the specified antenna gain of 49 dB and assuming an antenna efficiency of 80%, the 3 dB beamwidth is 0.75 degrees. Then the probability of a plane being in the main beam at a given instant is:

$$\text{Probability}\{\text{plane is in main beam}\} = \{1-\cos(0.5*0.75^{o})\}=2.14\text{x}10^{-5}$$

$$= 0.00214\%$$

Of course, this result does not apply if planes are *not* equilikely to be anywhere in the hemispheric field of view. An example of this would be if the CDA antenna is pointed at the flight path for a nearby airport. Note that if a plane is in the main beam of the CDA, it disrupts the satellite downlink anyway, so any reflected tag energy into the CDA is of no additional consequence.

Another View of the Problem

The above results are based on the assumption that the plane is equidistant from the tag and the CDA, i.e., that $R_1 = R_2$ in Figure A1. This will not always be the case, of course, so it is of interest to also examine the results when the plane's position ranges between that of the tag and that of the CDA. The results of this examination were surprising. One might surmise that the path loss via the plane reflection would be monotonic as the plane moves from the midpoint toward one end of the link, but this is not always the case. There *is*, at least, symmetry about the midpoint, of course.

The path loss vs. plane position was computed, measured as a percentage of the distance between the tag and the CDA (R1 + R2), assuming constant plane altitude, and with total ground range ($R_1 + R_2$) as a parameter. A plot of this data is shown in Figure A-2. This figure shows that for small ground range (i.e., smaller loss), the maximum loss occurs when the plane is at one end of the link. However, for large ranges and the same plane altitude, the *opposite* result occurs: the maximum loss occurs when the plane is at the midpoint of the range.

Furthermore, comparing the path losses for a range of 25 miles, we see that the path loss via the reflected path (via the plane) ranges between the values corresponding to the Hata model path loss for City and Suburban, so severe interference is a real possibility. However, for Open Area terrain, the Hata path loss is about 20 dB smaller than the reflection path loss, so interference would not be a problem for Open Area terrain.

Table A-4 Path Loss for Plane Height = 1 km

A/C height[km]= 1

Ground Range [km]	Reflected Path Loss [dB] with constant altitude & horizontal location (%) as a parameter										
	0	10	20	30	40	50	60	70	80	90	100
1	152.64	152.25	151.95	151.74	151.61	151.57	151.61	151.74	151.95	152.25	152.64
2	156.62	156.08	155.79	155.68	155.65	155.65	155.65	155.68	155.79	156.08	156.62
3	159.63	159.19	159.27	159.54	159.78	159.87	159.78	159.54	159.27	159.19	159.63
4	161.94	161.72	162.29	162.97	163.45	163.61	163.45	162.97	162.29	161.72	161.94
5	163.78	163.87	164.95	165.97	166.62	166.84	166.62	165.97	164.95	163.87	163.78
6	165.31	165.76	167.31	168.61	169.38	169.63	169.38	168.61	167.31	165.76	165.31
7	166.62	167.46	169.44	170.94	171.80	172.08	171.80	170.94	169.44	167.46	166.62
8	167.76	169.01	171.37	173.03	173.95	174.24	173.95	173.03	171.37	169.01	167.76
9	168.77	170.44	173.13	174.91	175.87	176.18	175.87	174.91	173.13	170.44	168.77
10	169.67	171.78	174.75	176.62	177.62	177.93	177.62	176.62	174.75	171.78	169.67
11	170.49	173.03	176.24	178.19	179.21	179.53	179.21	178.19	176.24	173.03	170.49
12	171.25	174.21	177.62	179.63	180.67	181.00	180.67	179.63	177.62	174.21	171.25
13	171.94	175.32	178.91	180.96	182.02	182.35	182.02	180.96	178.91	175.32	171.94
14	172.58	176.38	180.11	182.21	183.28	183.61	183.28	182.21	180.11	176.38	172.58
15	173.17	177.38	181.25	183.37	184.45	184.79	184.45	183.37	181.25	177.38	173.17
16	173.73	178.33	182.31	184.46	185.55	185.89	185.55	184.46	182.31	178.33	173.73
17	174.26	179.24	183.32	185.49	186.59	186.93	186.59	185.49	183.32	179.24	174.26
18	174.75	180.11	184.27	186.46	187.57	187.91	187.57	186.46	184.27	180.11	174.75
19	175.22	180.94	185.17	187.38	188.49	188.84	188.49	187.38	185.17	180.94	175.22
20	175.66	181.74	186.04	188.26	189.37	189.72	189.37	188.26	186.04	181.74	175.66
21	176.09	182.50	186.86	189.09	190.21	190.56	190.21	189.09	186.86	182.50	176.09
22	176.49	183.24	187.64	189.89	191.01	191.36	191.01	189.89	187.64	183.24	176.49
23	176.87	183.95	188.40	190.65	191.78	192.12	191.78	190.65	188.40	183.95	176.87
24	177.24	184.63	189.12	191.38	192.51	192.86	192.51	191.38	189.12	184.63	177.24
25	177.60	185.29	189.81	192.08	193.22	193.56	193.22	192.08	189.81	185.29	177.60

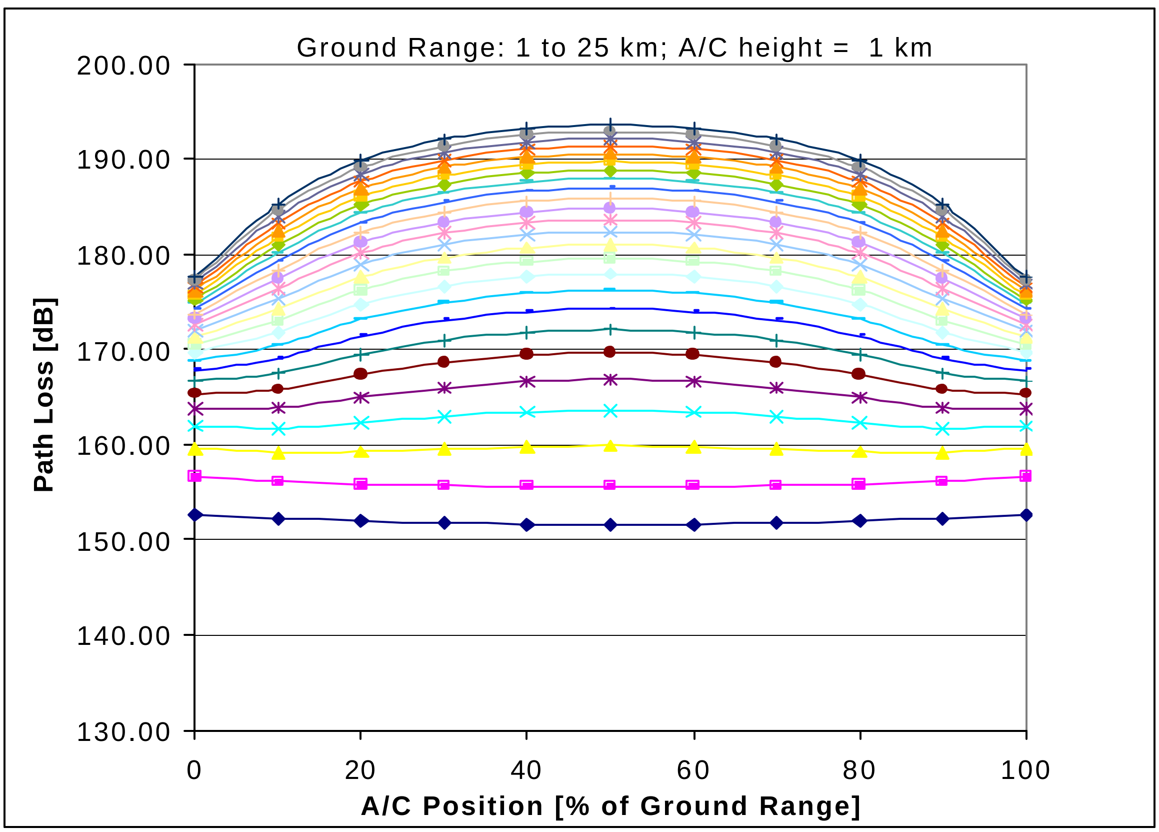


Figure A-2 Path Loss for Plane Height = 1 km

Now, if we change the plane height to 25 km, the path loss becomes concave up vs. plane position for large ground ranges (high path loss). The path loss is essentially constant for small ground range. These results are shown in Figure A-3. Note that the reflection path loss is greater than 200 dB in all cases, so there is no possibility of interference with the direct path (Hata model, city environment), until the ground range approaches 25 miles or so, at which point the S/I decreases to about 15 dB or so, which is still not a real problem.

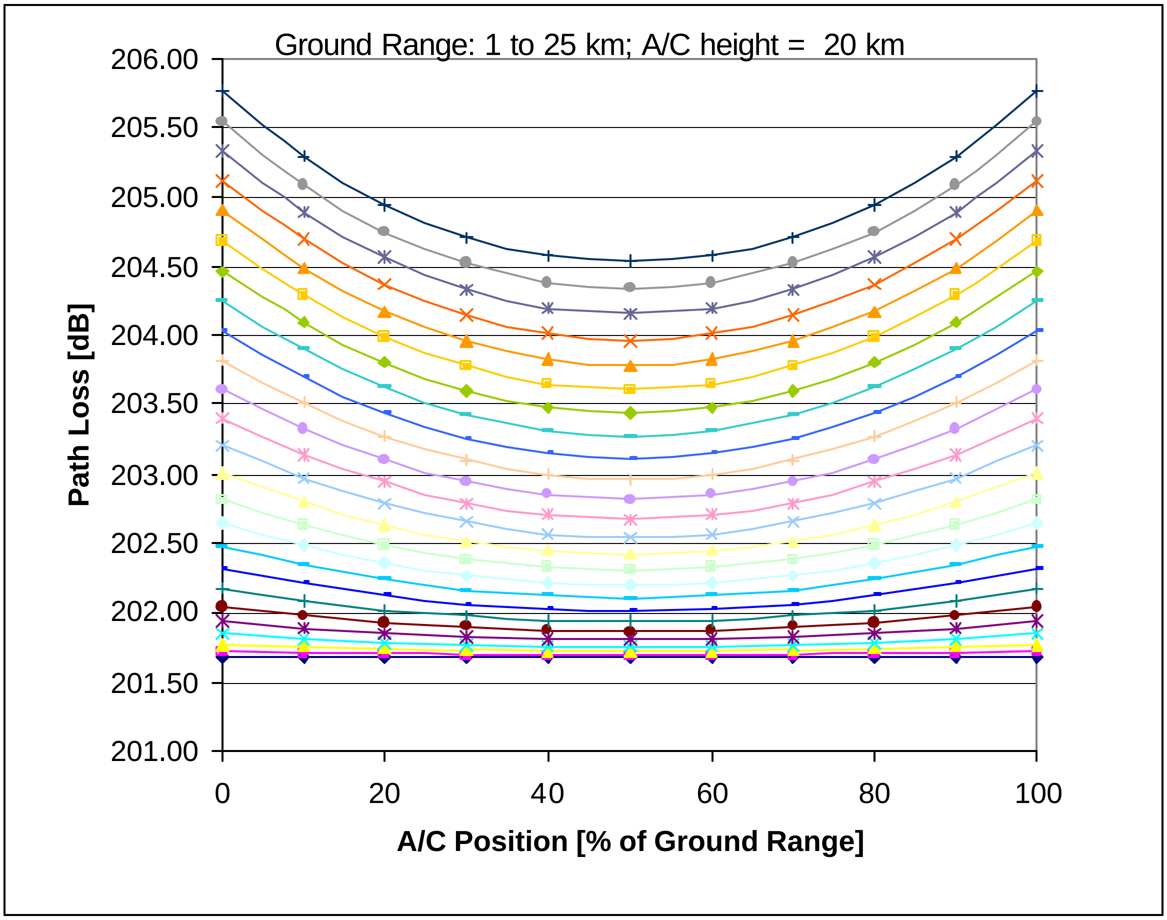


Figure A-3 Path Loss for Plane Height = 20 km

Now, if we change the plane height to an intermediate value, say, 10 km, the path loss becomes nonmonotonic as the plane moves from the midpoint to the end of the link, for the largeest ground ranges. As before, the path loss is essentially constant for small ground range. These results are shown in Figure A-4. Comparing these path losses to those of the Hata model, we see that, as before, there is no possibility of interference until the ground range approaches 25 miles (city environment), for which the S/I is about 9 dB, which could result in some degradation of BER.

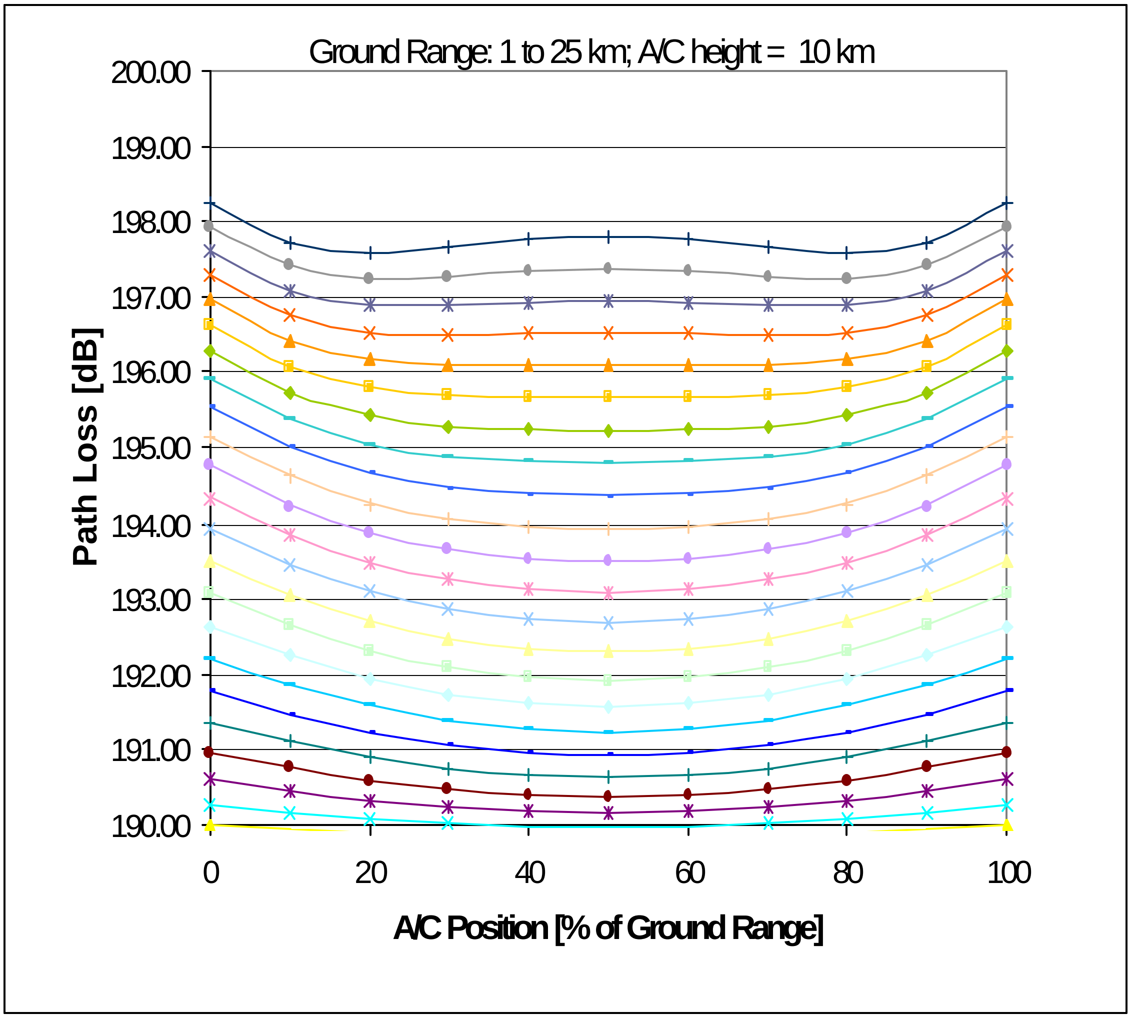


Figure A-4 Path Loss for Plane Height = 10 km

The three inflection points in Figure A-4 for the largest ranges were unexpected. Monotonic path loss changes with respect to the midpoint was the expected result. However, some further thought shows why three inflection points occur. Referring to Figure A-1, we can write:

$$R_1^2 = G_1^2 + h^2$$
$$R_2^2 = G_2^2 + h^2$$
$$G_1 = fR_3$$
$$G_2 = (1- f)R_3$$
$$L_{path} \propto R_1^2 R_2^2$$
$$\frac{\partial L_{path}}{\partial f} = f^3 - \frac{3}{2} f^2 + f(\frac{h^2}{2R_3^2} - \frac{1}{2}) - \frac{1}{2R_3^2} h^2 = 0$$

where *f* denotes the plane position as a fraction of the distance between the tag and the CDA (transmitter and receiver). Setting the partial derivative of the path loss with respect to f equal to zero allows us to solve the resulting cubic equation for three roots, which indicate where the three inflection points occur. This exercise has shown that there must, in the general case, be three inflection points in the path loss .

Appendix B: Emission Density

In the MATLAB simulation, N_e is defined the number of emissions per minute from an annular ring (annulus) of width 1 km and it is computed as the product of the effective ring area and the emission density, which is given in units of emissions per square km per minute. In the simulation, the value of N_e must be an integer. It makes quite a difference at low emission density values as to whether one rounds or truncates the non-integer product of emission density and ring area to obtain the integer number of emissions per ring per minute, N_e. This difference is illustrated by the results in Table B-1.

Table B-1 shows that the difference is not important for large values of emission density, but can be significant for small values (e.g., 0.02). Truncating yields a lower flux density at the CDA, but rounding is more appropriate (i.e, more accurate), and rounding was used for all the results reported in this TM. Table B-2 shows emissions per ring (based on rounding) for a range of effective emission densities. *Effective* emission density accounts for the fact that some fraction of the ring area may be devoid of emissions (over water or marsh, for example).

I have asserted that rounding is more accurate than truncating. However, rounding is not perfect. Note that due to the rounding operation performed on the product of emission density and ring area, the resulting N_e will be biased either high or low for small N_e values, where N_e is the number of emissions per minute from a ring or annulus, centered on the CDA. Raw N_e (i.e., prior to rounding) values in the interval [0,0.5) are rounded to 0, which gives optimistic (i.e., low) flux density values. Raw N_e values in [0.5,1) are rounded to 1, which gives pessimistic (i.e., high) flux density values. The same process operates for [1,1.5), [1.5, 2), etc. The percentage of the error (optimistic or pessimistic bias) decreases with increasing magnitude of N_e. This bias cannot be fixed in the simulation. One must be mindful of the bias when interpreting the results. This has no practically significant results for the cases presented in this TM, because we require a minimum exclusion radius of 6 km. This is the radius at which a single emitter produces a flux density at the CDA that exceeds the stated threshold level. It should be noted that it is permissible to violate this threshold level 0.01% of the time, or about 26 times per day.

Table B-1 Emissions/minute per Ring: Rounding vs. Truncating

Rounding vs. Truncating to nearest integer
for determining # of emissions per ring

		emission density=	*0.02*	*0.1*	*0.2*	*0.4*	*0.02*	*0.1*	*0.2*	*0.4*
			Round the # of emissions per ring				Truncate the # of emissions per ring			
Radius	**Ne(0.02)**	**Ring Area**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**
1	0.125664	6.28318531	0	1	1	3	0	0	1	2
2	0.251327	12.5663706	0	1	3	5	0	1	2	5
3	0.376991	18.8495559	0	2	4	8	0	1	3	7
4	0.502655	25.1327412	1	3	5	10	0	2	5	10
5	0.628319	31.4159265	1	3	6	13	0	3	6	12
6	0.753982	**37.6991118**	**1**	**4**	**8**	**15**	0	3	7	15
7	0.879646	43.9822972	1	4	9	18	0	4	8	17
8	1.00531	50.2654825	1	5	10	20	1	5	10	20
9	1.130973	56.5486678	1	6	11	23	1	5	11	22
10	1.256637	62.8318531	1	6	13	25	1	6	12	25
11	1.382301	69.1150384	1	7	14	28	1	6	13	27
12	1.507964	75.3982237	2	8	15	30	1	7	15	30
13	1.633628	81.681409	2	8	16	33	1	8	16	32
14	1.759292	87.9645943	2	9	18	35	1	8	17	35
15	1.884956	94.2477796	2	9	19	38	1	9	18	37
16	2.010619	100.530965	2	10	20	40	2	10	20	40
17	2.136283	106.81415	2	11	21	43	2	10	21	42
18	2.261947	113.097336	2	11	23	45	2	11	22	45
19	2.38761	119.380521	2	12	24	48	2	11	23	47
20	2.513274	125.663706	3	13	25	50	2	12	25	50
21	2.638938	131.946891	3	13	26	53	2	13	26	52

Table B2 Emissions/minute per Ring (Rounding Approach)

Round product of ring area and effective emission density
to determine # of emissions per ring Ne

		water factor x emission density=	*0.01*	*0.02*	*0.1*	*0.2*	*1*	*2*
			Round the # of emissions per ring					
Radius	**Ne for 0.01**	**Ring Area**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**	**Ne**
1	0.062831853	6.28318531	0	0	1	1	6	13
2	0.125663706	12.5663706	0	0	1	3	13	25
3	0.188495559	18.8495559	0	0	2	4	19	38
4	0.251327412	25.1327412	0	1	3	5	25	50
5	0.314159265	31.4159265	0	1	3	6	31	63
6	0.376991118	**37.6991118**	**0**	**1**	**4**	**8**	**38**	**75**
7	0.439822972	43.9822972	0	1	4	9	44	88
8	0.502654825	50.2654825	1	1	5	10	50	101
9	0.565486678	56.5486678	1	1	6	11	57	113
10	0.628318531	62.8318531	1	1	6	13	63	126
11	0.691150384	69.1150384	1	1	7	14	69	138
12	0.753982237	75.3982237	1	2	8	15	75	151
13	0.81681409	81.681409	1	2	8	16	82	163
14	0.879645943	87.9645943	1	2	9	18	88	176
15	0.942477796	94.2477796	1	2	9	19	94	188
16	1.005309649	100.530965	1	2	10	20	101	201
17	1.068141502	106.81415	1	2	11	21	107	214
18	1.130973355	113.097336	1	2	11	23	113	226
19	1.193805208	119.380521	1	2	12	24	119	239
20	1.256637061	125.663706	1	3	13	25	126	251
21	1.319468915	131.946891	1	3	13	26	132	264

Appendix C: MATLAB Code for Combination for Suburban Path Model

```
%    MicroTrax Simulation for Determination of Zone of Exclusion
%    April 13, 2000;     W. Adams 729-7779
%    Program file name: suburban.m

close all; clear all
%Input Parameter Value
%pause
maxnumplots=10000;            %number of simulation trials
FMHz=1676;                            %frequency in MHz
Ptx=0;                              %tag Tx power in dBW
txloss=5;                           %container or other loss imposed on tag transmitter
Txflux=Ptx-txloss-10*log10(4000);   %Tx flux [dBW/kHz]
Grx=4;                              %effective gain [dB] at Rx=49 (main lobe)-45 (sidelobe level)
p=0.08192*4/60;               %probability that a tx is on at a given instant in interval

%edensity =  %emissions/(sq km)/minute
edensityinner=0.02;
edensityouter=2;

rhobreakpoint=15;                   %Change edensity for Rkm<=breakpoint value
waterfactor=0.5;              %fractional reduction of area if part of it is water/marsh, etc.
Hb=15;                              %base antenna height in meters
Hm=1.5;                             %mobile antenna height in meters
Rmax=21;                                %range [km] beyond which diffraction loss becomes large
minRmin=1;
maxRmin=21;
coldim=(maxRmin-minRmin+1);         %number of minimum ranges to simulate
totfluxdb=zeros(maxnumplots,coldim)-1000;       %-1000 dBW is essentially zero power
tic                                 %start stopwatch timer
for plotindex=1:maxnumplots
 if mod(plotindex,100)==0
   plotindex
   toc
 end
for Rmin=minRmin:maxRmin
  ringflux=0;
  totflux=0;
  Rmin;
  for Rkm=Rmax:-1:Rmin
     %Path Loss computation    %(L=92.4+20*log10(Rkm)+20*log10(FGHz); %free space)
     %Note: Hata Model is a median loss model; std dev is 6 to 8 dB, lognormal pdf
     %Hata Path Loss Model with correction factors (CF)
     %Flcity=3.2*(LOG10(11.75*Hm))^2-4.97; %Large City CF
     Fsmcity=(1.1*LOG10(FMHz)-0.7)*Hm-(1.56*LOG10(FMHz)-0.8);      %small/medium city CF
     Fsuburban=2*(LOG10(FMHz/28))^2+5.4;     %modification for suburban area
     %Fopen=4.78*(LOG10(FMHz))^2-18.33*LOG10(FMHz)+40.98;    %mod for open area
     LHata=69.55+26.16*LOG10(FMHz)-13.82*LOG10(Hb)+(44.9-6.55*LOG10(Hb))*LOG10(Rkm);
     %Llc=LHata-Flcity;                   %loss for large city
     Lsmc=LHata-Fsmcity;                 %loss for small/medium city
     Lsuburban=Lsmc-Fsuburban;           %loss for suburban area
     %Lopen=Lsmc-Fopen;                  %loss for urban area
     %Generate # of simultaneous emissions from ring at Rkm range
```

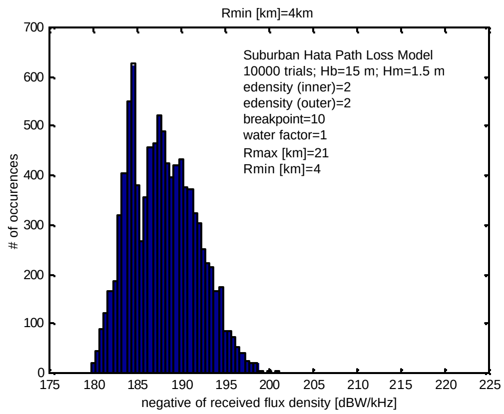
```
      if Rkm>rhobreakpoint
        edensity=edensityouter;
      else
        edensity=edensityinner;
      end
      Ne=round(2*pi*Rkm*waterfactor*edensity); %# emissions in Rth ring in 1-minute interval
      %draw a rv (i) corresponding to # of emitters simultaneously transmitting
      x=rand(1,Ne);        %row vector of uniform pdf RVs
      y=(x<p);             %row vector of indicator variables wrt threshold p
      i=sum(y);            %i is a RV with binominal distribution of values with parms N,p
      tagfluxdb=Txflux-Lsuburban+Grx;   %Rcvd flux for ONE tag at distance Rkm
      ringflux=i*10^(tagfluxdb/10);          %total flux density rcvd from ring at Rkm
      totflux=totflux+ringflux;              %accumulate flux contributions from each ring
    end     %end loop on radius Rkm
    if totflux~=0
    totfluxdb(plotindex,Rmin-minRmin+1)=10*log10(totflux);
       else
    totfluxdb(plotindex,Rmin-minRmin+1)=NaN;
       end
    %each element of totfluxdb is cumulative flux based on different Rmin
  end %end loop on Rmin
  plot(minRmin:maxRmin,totfluxdb(plotindex,:))   %flux vs. Rmin (minRmin,...maxRmin)
  hold on
  end       %end loop on number of plots (i.e., number of trials)
  xlabel('Choice for Rmin [km]')
  ylabel('Received Flux [dBW/kHz]')
  plottop=max(max(totfluxdb))
  text((1.2*maxRmin-minRmin)/2,plottop-5,{'Suburban Hata Path Loss Model' ,...
     '10000 trials; Hb=15 m; Hm=1.5 m' ,['edensity (inner)=',num2str(edensityinner)],...
     ['edensity (outer)=',num2str(edensityouter)],...
     ['breakpoint=',int2str(rhobreakpoint)],...
     ['water factor=',num2str(waterfactor)],'Rmax [km]=21', ['Rmin [km]=',int2str(Rmin)]})
  hold off
  totfluxdb
  toc                              %stop stopwatch timer
  %pause
  saveas(gcf,['fluxdensity vs Rmin.fig'])

  x=-(-180:-0.5:-220);
  totfluxdb=-totfluxdb;
  [N,x]=hist(totfluxdb,x)

  z=max(N)          %row vector containing the max bar height within each of the histograms
  for histo=1:maxRmin-minRmin+1
    histo
    Rminvalue= minRmin+histo-1
    figure(histo)
    hist(totfluxdb(:,histo),x)
    xlabel('negative of received flux density [dBW/kHz]')
    ylabel('# of occurences')
  title(['Rmin [km]=',int2str(Rminvalue), 'km'])
  text(x(1)-5+3,(z(histo)*4/5),{'Suburban Hata Path Loss Model' ,...
     '10000 trials; Hb=15 m; Hm=1.5 m' ,['edensity (inner)=',num2str(edensityinner)],...
     ['edensity (outer)=',num2str(edensityouter)],...
     ['breakpoint=',int2str(rhobreakpoint)],...
     ['water factor=',num2str(waterfactor)],'Rmax [km]=21',...
```

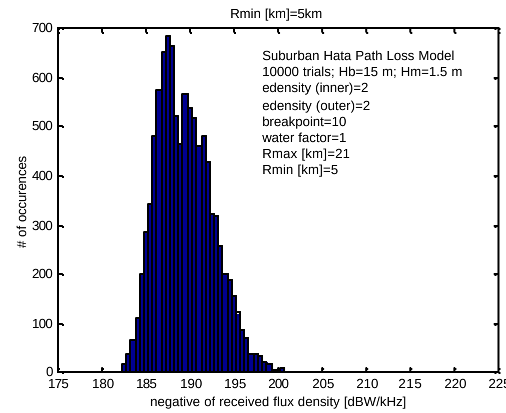
```
    ['Rmin [km]=',int2str(Rminvalue)]})
saveas(gcf,['Rmin ',int2str(Rminvalue),'.fig'])

end
```

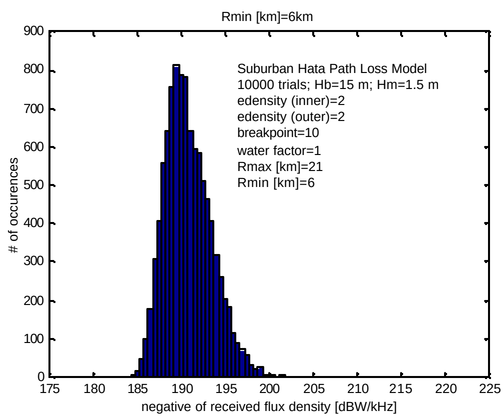
Appendix D: Simulation Results for Various Scenarios

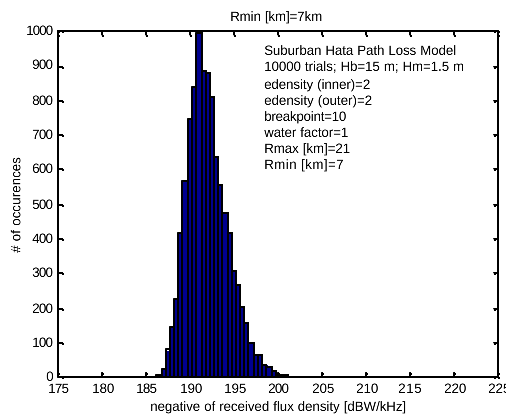
This appendix documents histogram outputs of the MicroTrax MATLAB simulation for a variety of emission densities and water factors.

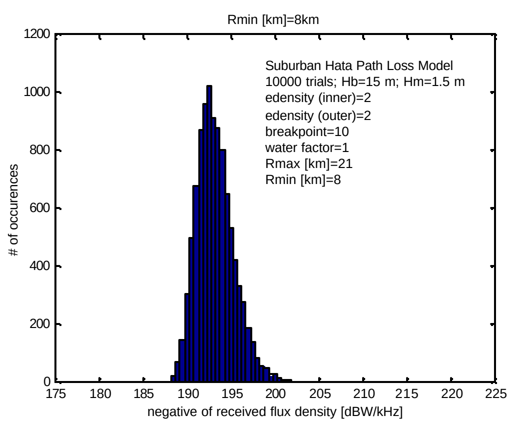
Suburban: Emission density = 2 and no water

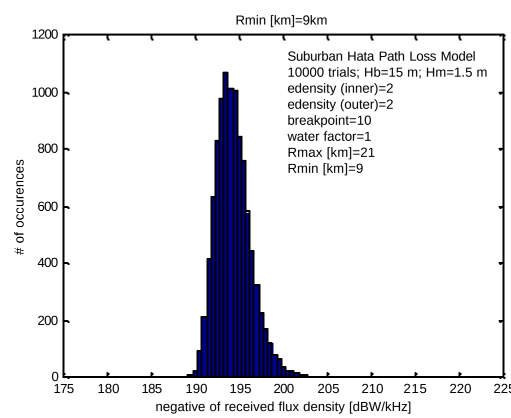


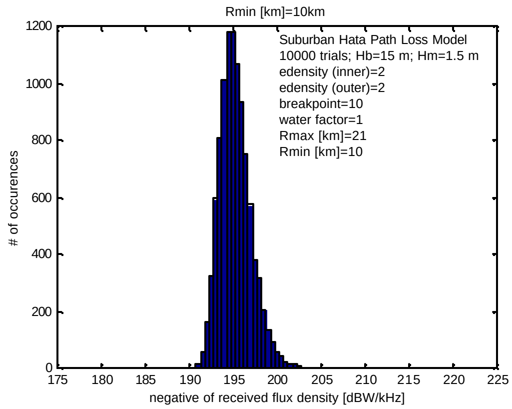


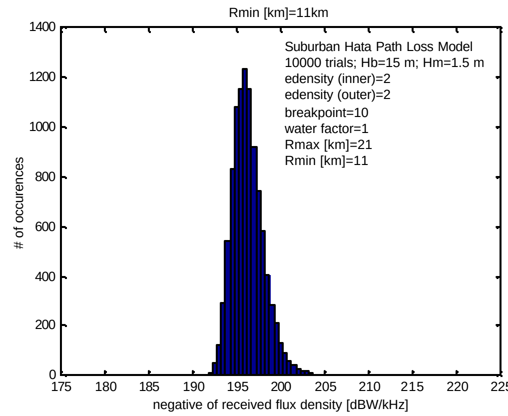


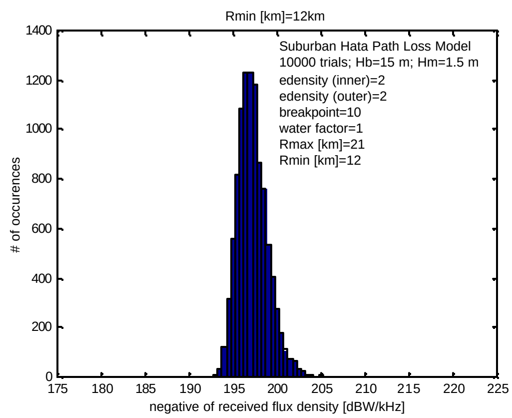


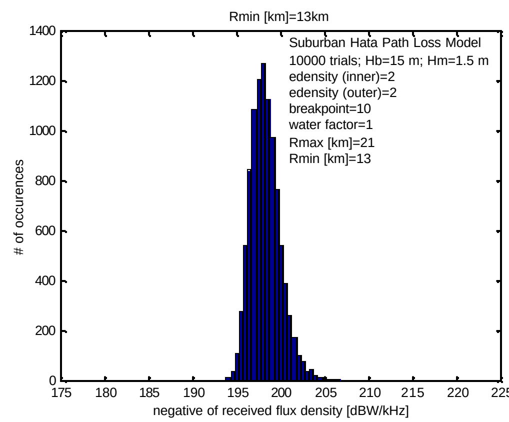


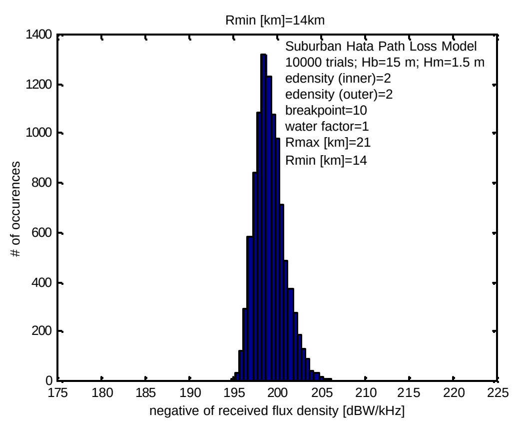


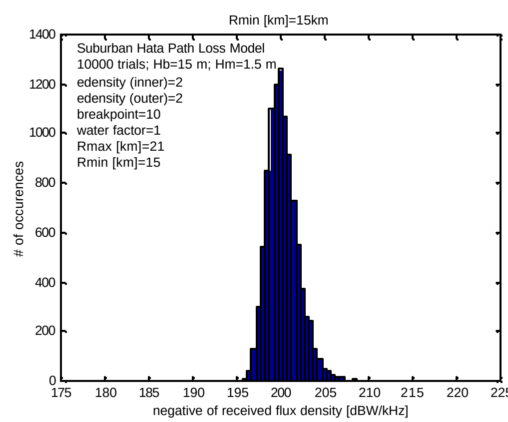

Rmin [km]=10km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=10
# of occurences
negative of received flux density [dBW/kHz]

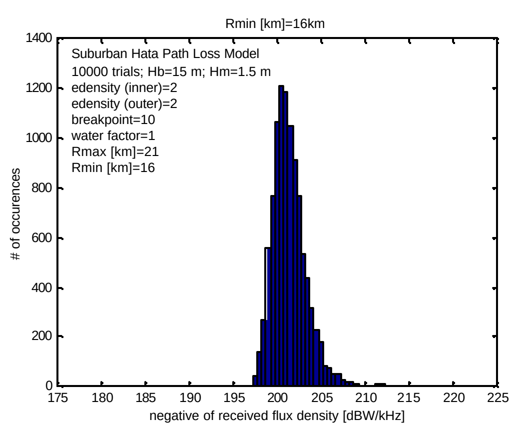

Rmin [km]=11km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=11
# of occurences
negative of received flux density [dBW/kHz]

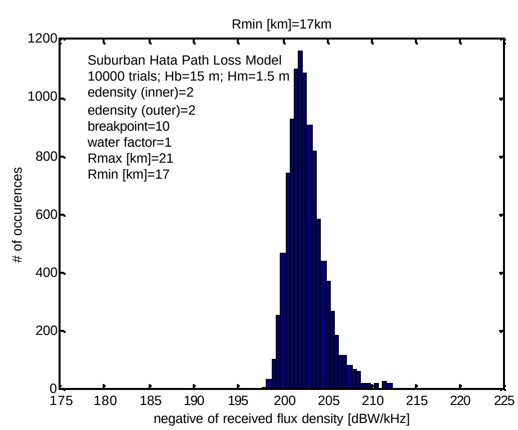

Rmin [km]=12km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=12
# of occurences
negative of received flux density [dBW/kHz]

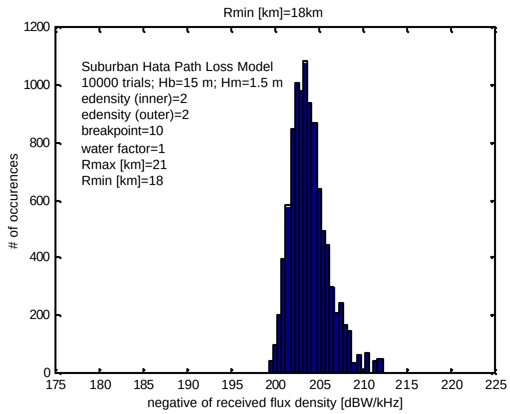

Rmin [km]=13km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=13
# of occurences
negative of received flux density [dBW/kHz]

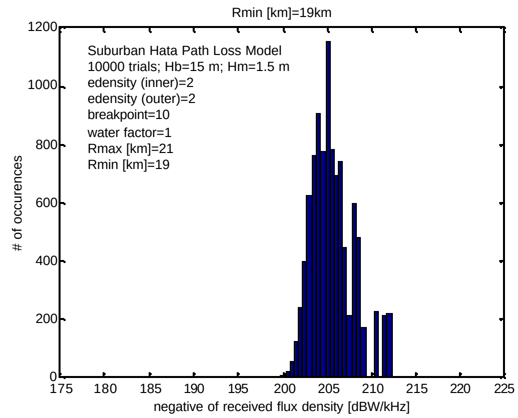

Rmin [km]=14km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=14
# of occurences
negative of received flux density [dBW/kHz]

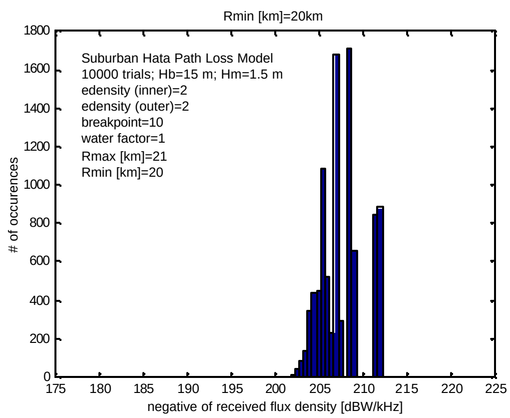

Rmin [km]=15km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=15
# of occurences
negative of received flux density [dBW/kHz]

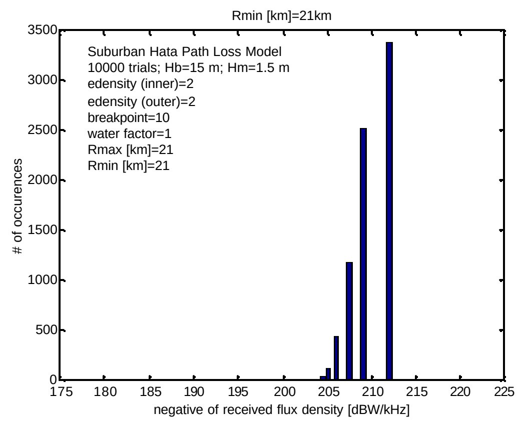

Rmin [km]=16km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=16
# of occurences
negative of received flux density [dBW/kHz]


Rmin [km]=17km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=17
# of occurences
negative of received flux density [dBW/kHz]

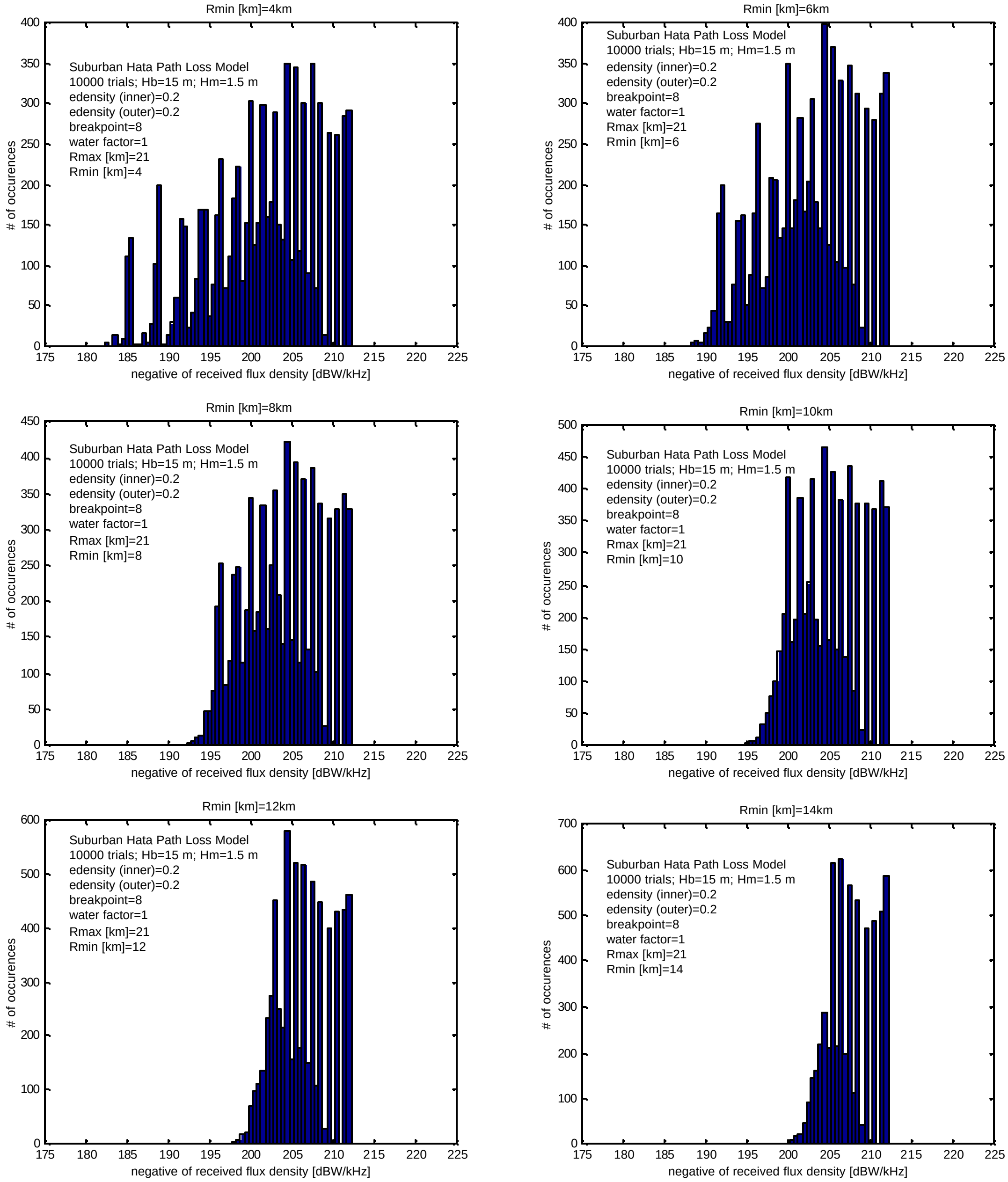

Rmin [km]=18km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=18
# of occurences
negative of received flux density [dBW/kHz]

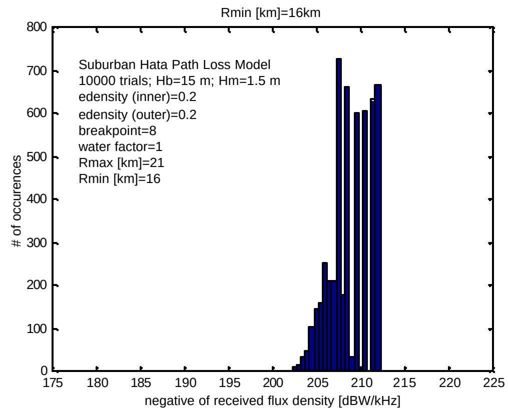

Rmin [km]=19km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=19
# of occurences
negative of received flux density [dBW/kHz]

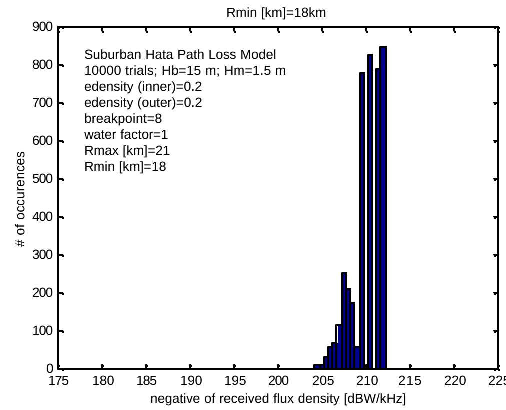

Rmin [km]=20km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=20
# of occurences
negative of received flux density [dBW/kHz]

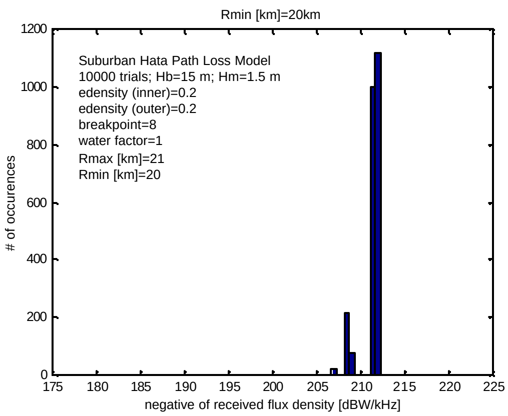

Rmin [km]=21km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=2
edensity (outer)=2
breakpoint=10
water factor=1
Rmax [km]=21
Rmin [km]=21
# of occurences
negative of received flux density [dBW/kHz]

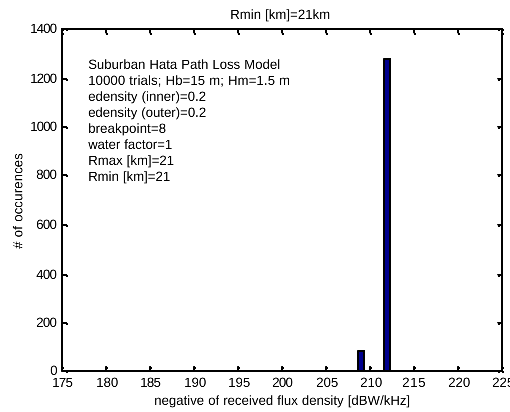
Suburban: Emission density = 0.2 and no water



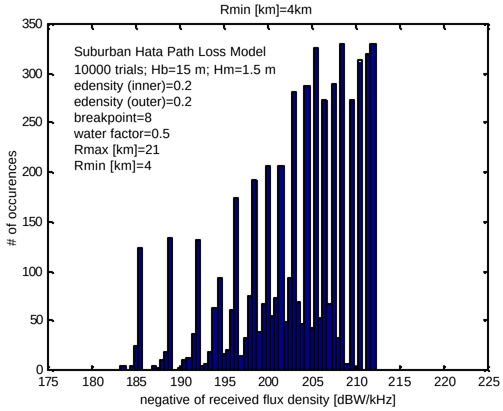

Rmin [km]=16km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=1
Rmax [km]=21
Rmin [km]=16
# of occurences
negative of received flux density [dBW/kHz]

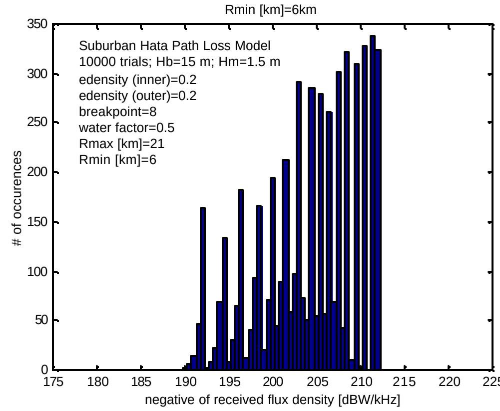

Rmin [km]=18km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=1
Rmax [km]=21
Rmin [km]=18
# of occurences
negative of received flux density [dBW/kHz]

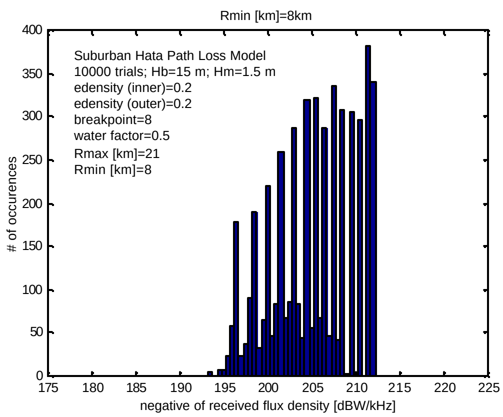

Rmin [km]=20km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=1
Rmax [km]=21
Rmin [km]=20
# of occurences
negative of received flux density [dBW/kHz]

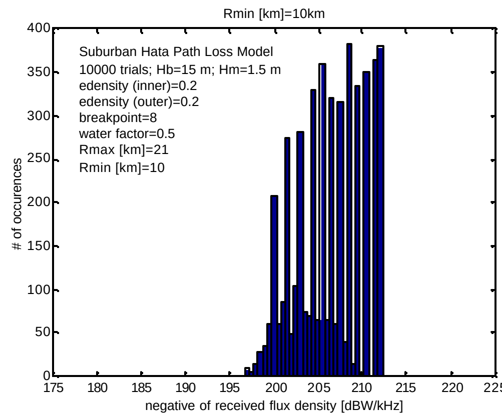

Rmin [km]=21km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=1
Rmax [km]=21
Rmin [km]=21
# of occurences
negative of received flux density [dBW/kHz]

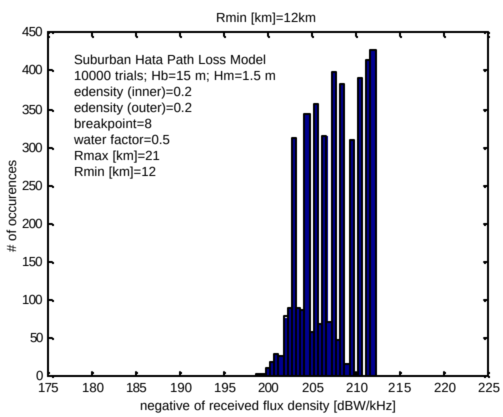
Suburban: Emission density = 0.2 and 50% water

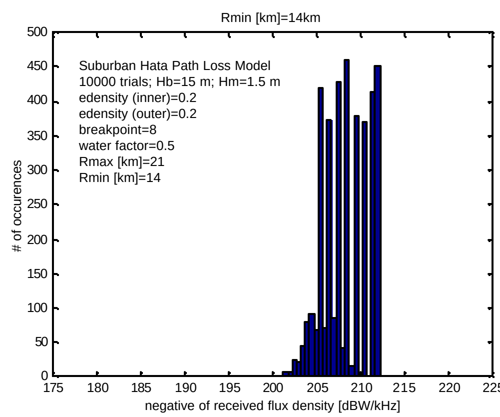


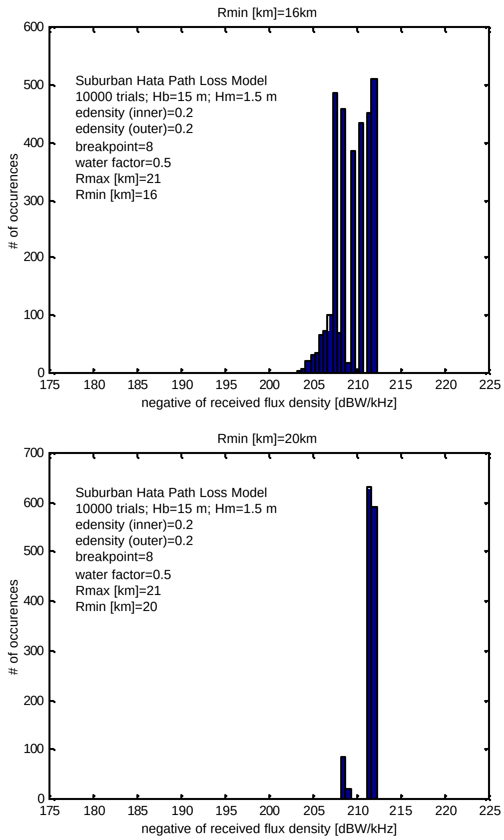




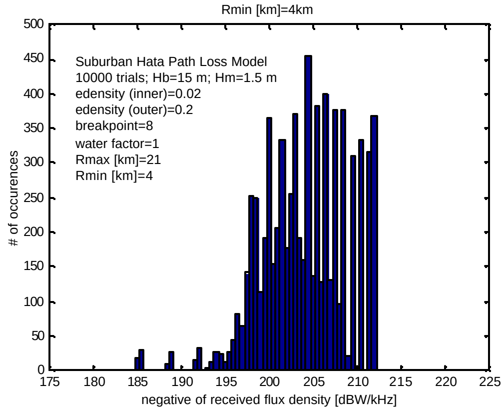


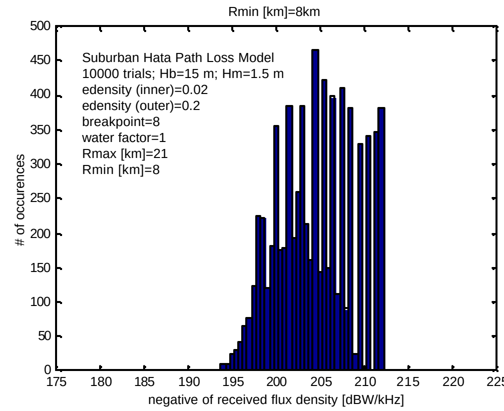


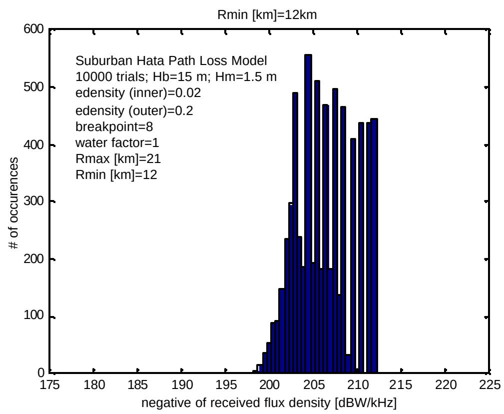


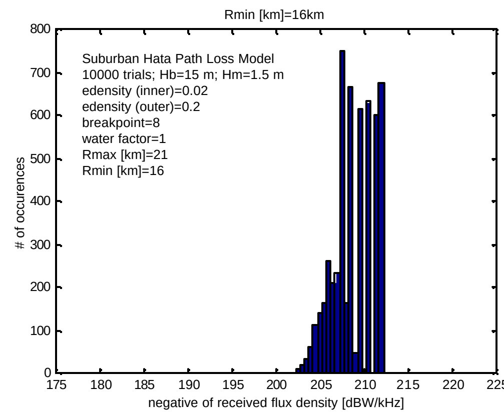

Rmin [km]=16km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=0.5
Rmax [km]=21
Rmin [km]=16
# of occurences
negative of received flux density [dBW/kHz]
Rmin [km]=18km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=0.5
Rmax [km]=21
Rmin [km]=18
# of occurences
negative of received flux density [dBW/kHz]
Rmin [km]=20km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=0.5
Rmax [km]=21
Rmin [km]=20
# of occurences
negative of received flux density [dBW/kHz]
Rmin [km]=21km
Suburban Hata Path Loss Model
10000 trials; Hb=15 m; Hm=1.5 m
edensity (inner)=0.2
edensity (outer)=0.2
breakpoint=8
water factor=0.5
Rmax [km]=21
Rmin [km]=21
# of occurences
negative of received flux density [dBW/kHz]

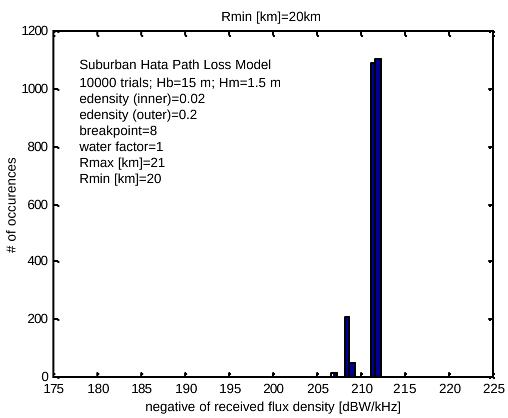
Suburban: Emission density=0.02 & 0.2, breakpoint=8 km and no water

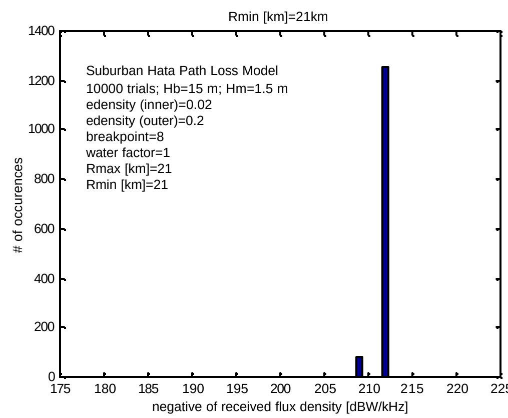




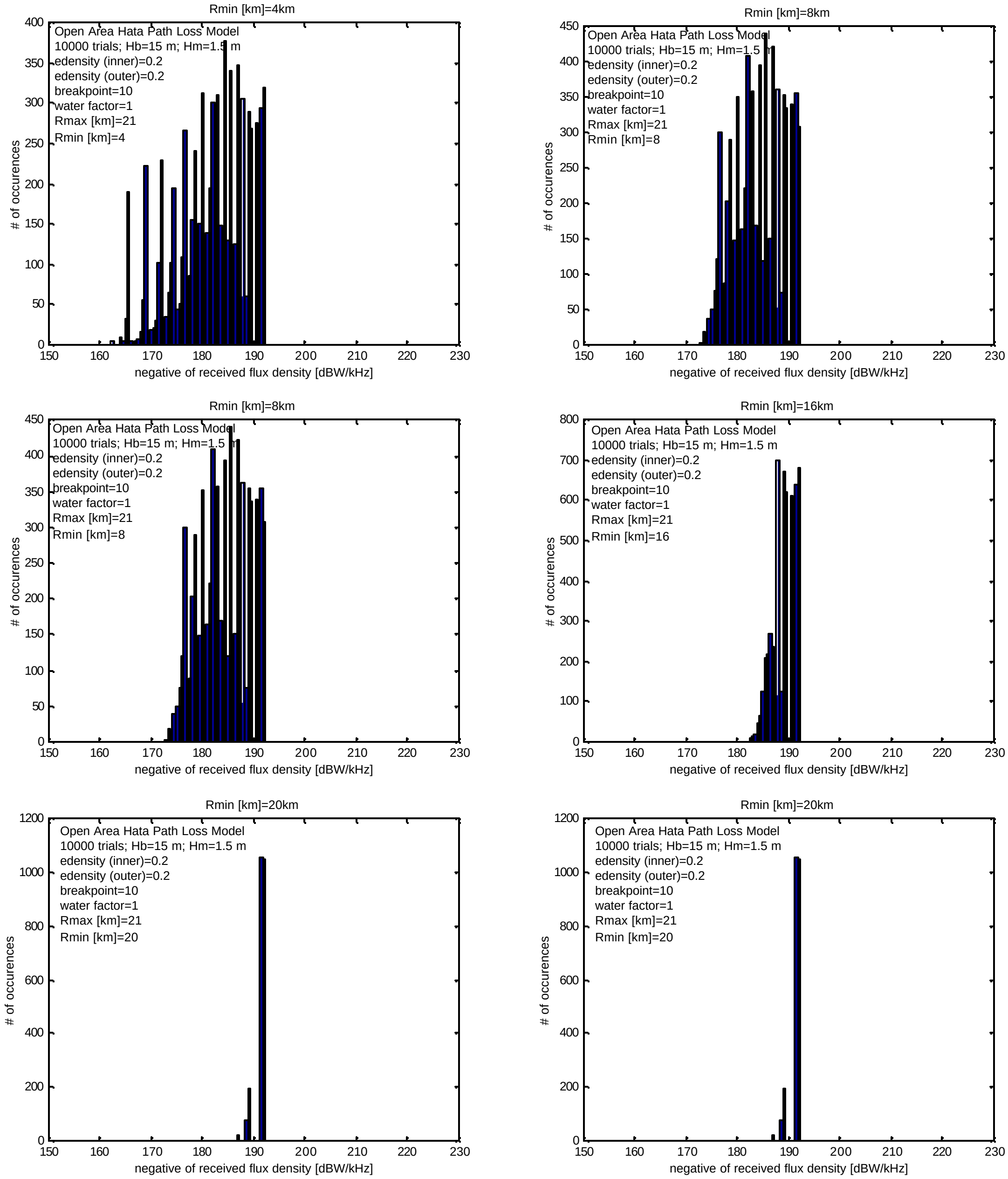








Open Area: Emission density = 0.2, and no water



Open Area: Emission density = 0.02, and half water